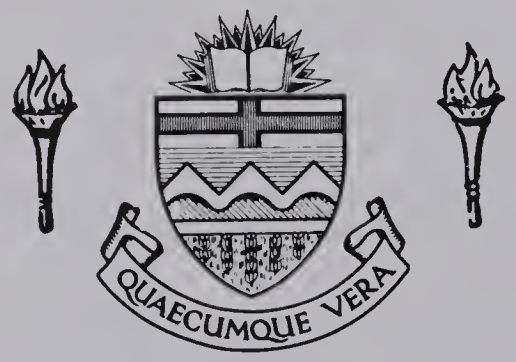
For Reference

NOT TO BE TAKEN FROM THIS ROOM

Ex libris
universitatis
albertaensis



THESIS 5701

T H E U N I V E R S I T Y O F A L B E R T A

RELEASE FORM

NAME OF AUTHOR ALAN R. SNEYD

TITLE OF THESIS WATERSHED MANAGEMENT IN THE KANANASKIS DISTRICT EAST SLOPES, ALBERTA

DEGREE FOR WHICH THESIS WAS PRESENTED M.Sc.

YEAR THIS DEGREE GRANTED 1982

Permission is hereby granted to THE UNIVERSITY OF ALBERTA LIBRARY to reproduce single copies of this thesis and to lend or sell such copies for private, scholarly or scientific research purposes only.

The author reserves other publication rights, and neither the thesis nor extensive extracts from it may be printed or otherwise reproduced without the author's written permission.

THE UNIVERSITY OF ALBERTA

WATERSHED MANAGEMENT IN THE KANANASKIS DISTRICT, EAST SLOPES, ALBERTA

by

ALAN R. SNEYD

C

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILMENT OF THE REQUIREMENTS FOR THE DEGREE

OF MASTER OF SCIENCE

DEPARTMENT OF GEOGRAPHY

EDMONTON, ALBERTA

FALL, 1982

GF - N4

THE UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research, for acceptance, a thesis entitled ...WATERSHED MANAGEMENT IN.....
THE KANANASKIS DISTRICT, EAST SLOPES, ALBERTA.....
.....
submitted by...ALAN R. SNEYD.....
in partial fulfilment of the requirements for the degree of
Master of ...Science.....

To: Lynne

ABSTRACT

Watershed management of the Eastern Slopes of Alberta has been a high priority in successive Provincial government policies governing land and resource use of this region. Traditionally, the watershed has been viewed as a supplier of water and this yield orientation is evident in the current policy which has as its main objective watershed protection. Without a regional analysis to identify the nature of water supply and demand orientations, it is not reasonable to expect that watershed protection need apply to all areas. Other management objectives including regime improvement, water quality improvement, flood reduction, erosion and sedimentation limitations, and stream environment improvement might be more regionally appropriate.

The objective in this study is to develop and discuss water management alternatives for the Kananaskis District. In Chapter 1, the topic of water management is introduced and some prospective problems are presented. The literature review in Chapter 2 includes a discussion of past and existing management structures and demand configurations. The physical basin and water supply characteristics are analyzed in Chapter 3 and 4 and new maps of precipitation and runoff are developed. The effects which varying water management objectives would have on each of the major water-based demands is described and summarized in Chapter 5 and 6.

The potential for yield improvement was estimated from precipitation-vegetation relationships to be small and of questionable merit since the required measures would conflict with existing land use policies. Regime improvement is compatible with current land use policies since it relies, in part, upon forest preservation through fire protection. Structural manipulation of the reservoirs offers the best opportunity for regime improvement. The instream flow methodology described recommends consistent instantaneous flow levels of 6.5 cms to sustain good conditions for fish and aquatic habitat, and for water-based recreation

during the summer period. Reservoir levels could be linked to stream-flow stage levels using a methodology similar to the zoning and rule curve method described so that violation in storage and flow are minimized. The regular, instantaneous flows characteristic of regime improvement are in conflict with the current peaking strategy of Trans-Alta Utilities, although no actual loss in hydro generation need occur. Regime improvement will complement external instream flow requirements above Calgary and municipal demand requirements and in theory aids instream flow needs below Calgary as well as irrigation demands. Any real benefit to instream flow requirements through higher summer flows below Calgary could be easily minimized by further irrigation withdrawals. Border flow requirements are not compatible with regime improvement since redistributed flows in summer could reduce winter flows below the requisite levels. Apportionment would only be adversely affected if the redistributed flows were consumed by the irrigation districts. Other potential water management objectives were found to be compatible with regime improvement.

Several options and potential tradeoffs are discussed which could be used to compensate for the loss of peaking power if regime improvement were to be adopted.

ACKNOWLEDGEMENT

There are several individuals who provided information or services and I would like to acknowledge their assistance at this time. From Alberta Environment, Mr. J. Glenn, Mr. W. Dybvig and Mr. N. Briggs offered advice on water supply and demand characteristics in the Bow River basin. Mr. L. Coulson of Alberta Energy and Natural Resources provided elaboration on government land and water policies in the Kananaskis. Mr. P. Taylor of Alberta Parks and Recreation discussed the nature of the fisheries problem in the Kananaskis.

Mr. T. Shulte and later Mr. P. Doyle of TransAlta Utilities suffered repeated requests for data and records. Mr. D. Harrison of the City of Calgary was most generous with his time and provided advice and perspective on municipal water supply and demand problems. Mr. G. Hillman of the Canadian Forestry Service and Mr. D. Golding of the University of B.C. provided the forestry perspective, and offered me the opportunity to participate in the Marmot Creek snow survey in March 1978.

Mrs. S. Stonehouse, Mrs. L. Sneyd and Mrs. M. Hibbs typed the draft and final thesis copy. Ms. D. Morin and Mrs. L. Sneyd assisted with several of the drawings.

Finally, I would like to thank my committee, Dr. R. Rothwell, Dr. E. Jackson and Dr. A. Laycock for offering constructive suggestions and advice. A special thanks to my supervisor, Dr. A. Laycock, who offered the encouragement necessary to keep the production rolling.

Lastly, I would like to thank my wife, Lynne Sneyd, who has offered advice, criticism, encouragement, and who has given so much of her time and assistance throughout the duration of this project.

TABLE OF CONTENTS

		Page
Library Release Form		(i)
Title Page		(ii)
Signed Approval Page		(iii)
Dedication		(iv)
Abstract		(v)
Acknowledgement		(vii)
Table of Contents		(viii)
List of Tables		(xi)
List of Figures		(xiii)
Chapter		
1.0	Introduction	1
1.1	Problems Definition	1
1.1.1.	General Perspective	1
1.1.2.	Water and Resource Planning in the Eastern Slopes	3
1.1.3.	Need for a Regional Analysis	5
1.2	Study Objective and Procedures	7
1.2.1.	Study Objectives	7
1.2.2.	Assessment of Management Demands	9
1.2.3.	Physical - Climatic Analysis	10
1.2.4.	Water Supply Analysis	11
1.3	The Study Area	12
1.3.1.	Geographic Perspective	12
1.3.2.	Physiography	15
1.3.3.	Bedrock Geology	19
1.3.4.	Surficial Materials	23
1.3.5.	Drainage Characteristics	33
1.3.6.	Climate	37
1.3.7.	Vegetation	39
2.0	Literature Review	44
2.1	East Slopes Perspective	44
2.1.1.	Water Management in the Eastern Slopes	44
2.1.2.	The Alberta (East Slopes) Watershed Research Program	54

Page

2.2 Management of the Kananaskis District 61

2.2.1. Administration and Water Management. 61
2.2.2. Water and Land Use Demand Assessment 73
2.2.3. Summary of Demand Assessment 104

2.3 Regional Analysis Methodology. 109

2.3.1. Potential Water Management Objectives 109
2.3.2. Watershed Soils Classification 114
2.3.3. Climate Analysis 119
2.3.4. Hydrologic Analysis 122

3.0 Climate Analysis 125

3.1 Geographic Aspects of Macro-Climatic Patterns 125

3.1.1. Latitude. 125
3.1.2. Continental Location. 126
3.1.3. Intervening Mountain Ranges 127
3.1.4. Air Mass Characteristics 128

3.2 Physiographic Influences on Selected Climatic Elements 130

3.2.1. Radiation 130
3.2.2. Temperature 137
3.2.3. Precipitation 147
3.2.4. Evapotranspiration 154

3.3 Kananaskis Precipitation Characteristics 158

3.3.1. Frequency 160
3.3.2. Intensity and Duration 163
3.3.3. Snowfall and Snowcover 172
3.3.4. Average Annual Precipitation Patterns 190

3.4 Climatic Summary 194

4.0 Hydrologic Analysis 198

4.1 Groundwater. 198

4.1.1. Hydrogeology 198
4.1.2. Groundwater Discharge Phenomenon 201
4.1.3. Groundwater - Streamflow Relationship 202
4.1.4. Groundwater Summary 207

Page

4.2 Runoff Variations 208

4.2.1. Seasonal Patterns 208
4.2.2. Spatial Patterns of Runoff 213
4.2.3. Total Runoff: Normal and Extreme Conditions . . 224

4.3 Streamflow Characteristics 227

4.3.1. Natural Flow 227
4.3.2. Post-Development Streamflow Conditions 232
4.3.3. Contemporary Streamflow Patterns 238

4.4 Surface Storage in Lakes and Reservoirs 243

4.4.1. Pre-Development Conditions 243
4.4.2. Reservoir Development Period 245
4.4.3. Contemporary Storage Patterns 246

4.5 Hydrologic Summary 253

5.0 Water Management Assessment 258

5.1 Water Supply Characteristics 258

5.1.1 Intra-Regional Climatic and Water Supply Patterns 258
5.1.2. Total Water Supply Characteristics 261

5.2 Water Demand Characteristics 262

5.2.1. Internal Water Demand Requirements 263
5.2.2. External Water Demand Requirements 283

5.3 Assessment of Water Management Alternatives 298

5.3.1. Choosing a Regionally-Based Water Management Objective 298
5.3.2. Alternative Strategies in Water Management 316

6.0 Conclusions and Recommendations 356

6.1 Conclusions 356

6.2 Recommendations 364

Bibliography 370

LIST OF TABLES

		Page
1.3a	Rock Units and Lithologies in the Kananaskis District .	20
1.3b	Surficial Materials and Terrain Units in the Kananaskis District as Mapped by Osborn and Jackson (1974). . . .	26
1.3c	Total Area of Forest Cover Types in the Kananaskis Valley	41
2.1a	Permitted Activities by Land Use Zones	51
2.2a	Generating Capacity of Power Plants by Type and Energy Resource, 1980	82
2.2b	Assumed Hectares Irrigated, Gross Diversions and Return Flows, Western, Bow River and Eastern Irrigation Districts	92
2.2c	Forecasted Annual Demand - City of Calgary	97
2.2d	Forecasted Monthly Water Consumption - City of Calgary 1980 - 2001	99
3.2a	Average Number of Hours of Bright Sunlight	136
3.2b	Monthly and Annual Mean and Extreme Temperatures at E.S.C., PLO, MARMOT (CON 5), B.R.S. and KLO	142
3.2c	Unadjusted Mean Monthly Totals of Evaporation for Stations in Marmot Creek	155
3.3a	Rainfall Intensity and Duration Values for Kananaskis E.S.C.	164
3.3b	Extreme Rainfall Intensities for Kananaskis E.S.C., Marmot Creek (CON 5) and Kananaskis Lookout (K.L.O.) . .	165
3.3c	Mean Monthly and Extreme 24-hour Snowfalls at Kananaskis E.S.C.	171
3.3d	Mean Annual, Extreme Minimum and Extreme Maximum Runoff Values for Selected Drainage Units, Kananaskis District	192

		Page
4.1a	Typical Plant Association in Groundwater Discharge Areas in the Kananaskis District	203
4.2a	Percent Distribution of Normal Runoff by Months for the Years 1912 - 1932 Inclusive, Kananaskis District .	209
4.2b	Percent Distribution of Regulated Runoff by Months for the Years 1933 - 1962 Inclusive, Kananaskis District	212
4.3a	Descriptive Measures of Average Daily Streamflow During Natural (1911 - 1932) and Post-Development (1933 - 1962) Periods for the Kananaskis River	235
4.4a	Natural and Artificial Lake Levels in Kananaskis District	247
5.2a	Hydroelectric Energy Stored in Kananaskis District Reservoirs at Month End in 1980 and 1981	268
5.2b	Net Annual Generation (GWh) of the Kananaskis District Hydro Plants 1970 - 1980.	269
5.2c	Instream Flow Regimens for Fish, Wildlife, Recreation and Related Environmental Resources	275
5.3a	Potential Water Management Objectives and Alternative Techniques for use in the Kananaskis District.	302
5.3b	Compatibility Matrix of Various Water Management Objectives in the Kananaskis District and Water-Based Demands	355

LIST OF FIGURES

		Page
1.3a	Location Map - Study Area	13
1.3b	Percent of Area Below Indicated Elevation	18
1.3c	Bedrock Geology	22
1.3d	Surficial Geology	29
1.3e	Drainage	34
1.3f	Stream Profile	36
1.3g	Vegetation	42
2.2a	Administration of the Kananaskis District	65
2.2b	Resource Zone Map of the Kananaskis District	67
2.2c	Kananaskis Provincial Park	71
2.2d	Contemporary Seasonal Streamflow Patterns of Kananaskis River above Pocaterra Creek, 1975 -1979	79
2.2e	Contemporary Daily Streamflow Patterns of the Kananaskis River Above Pocaterra Creek, 1977	79
2.2f	Growth of Irrigated Hectares in the Eastern, Bow River and Western Irrigation District, 1972 - 1980	87
2.2g	Hydrograph of Monthly Diversions for Eastern, Bow River and Western Irrigation Districts, 1979	89
2.2h	Total Diversion and Consumptive Water Use by Eastern, Bow River and Western Irrigation Districts in 1979	90
2.3a	Watershed Soils Map - Kananaskis District	120

Page

3.2a Variability of Clear Sky Effective Incoming Short-Wave Radiation at Marmot Creek - June 22 131

3.2b Variability of Clear Sky Effective Incoming Short-Wave Radiation at Marmot Creek - December 22 132

3.2c Effect of Season and Topographic Shading on Net Radiation at Marmot Creek 134

3.2d Mean Daily Incoming Short-Wave Radiation at Marmot Creek 135

3.2e Temperature Recording Stations 141

3.2f Mean Monthly Temperature Curves 143

3.2g Elevation - Temperature Relationship (Marmot Creek Area) 146

3.2h Average Annual Precipitation - Elevation Relationship in and Adjacent to the Mountain National Parks 150

3.2i Average Annual Snowfall as Percentage of Average Annual Precipitation, Banff and Jasper National Park Snow Courses 152

3.3a Precipitation Frequency and Amount - Kananaskis E.S.C. 161

3.3b Rainfall Intensity vs Elevation on East Slopes of the Rockies 166

3.3c Frequency Analysis of Annual Maximum of 24-hour Snowfalls at CON 5, Marmot Creek 168

3.3d 1941 - 1970 Precipitation Intensity and Duration Statistics - Kananaskis E.S.C. 170

3.3e Snowfall Measurement Sites 173

3.3f Mean Winter Snowfall Water Equivalent, 1963 - 1973, in Marmot Creek 176

3.3g Snow Course Locations - Kananaskis District 180

3.3h Average Snow Water Equivalent vs Elevation for Marmot Creek Snow Courses in April, Kananaskis District 181

		Page
3.3i	Average Snow Water Equivalent for all Snow Courses in Kananaskis District	183
3.3j	Location of Snow Pillows - Marmot Creek	186
3.3k	Snow Pillow Traces for High Snowfall Year - 1974	187
3.3l	Snow Pillow Traces for Low Snowfall Year - 1977	188
3.3m	Estimated Average Annual Precipitation - Kananaskis District	195
4.1a	Relationship Between Storage, Streamflow and Mean Daily Streamflow at Marmot Creek	205
4.1b	Relationship Between Subsurface Storage and Streamflow at Marmot Creek	206
4.2a	Seasonal Variations in Runoff of Two Small Unregulated Streams	211
4.2b	Estimated Average Annual Runoff - Kananaskis District	215
4.2c	Percent Average Natural Runoff from Kananaskis District	220
4.2d	Total Annual Discharge for Kananaskis River Below Barrier Reservoir	226
4.3a	Discharge Summary 1911 - 1932, Kananaskis River	229
4.3b	Monthly Duration Curves, Kananaskis River	231
4.3c	Regulated Flow Summary - Kananaskis River 1933 - 1962	233
4.3d	Seasonal Variation of Monthly Mean Streamflow for the Kananaskis River Above Pocaterra Creek	237
4.3e	Seasonal Streamflow Patterns of the Kananaskis River Below Barrier Reservoir, 1975 - 1979	240
4.3f	Daily Streamflow Variations of the Kananaskis River Below Barrier Reservoir, July 1977	240

		Page
4.3g	Seasonal Streamflow Patterns of Kananaskis River Above Pocaterra Creek, 1975 - 1979	242
4.3h	Daily Streamflow Variations of the Kananaskis River Above Pocaterra Creek, July - September 1977	242
4.4a	Monthly Mean Water Levels for Barrier Reservoir, 1969 - 1980	249
4.4b	Monthly Mean Water Levels for Lower Kananaskis Lake, 1969 - 1980	250
4.4c	Monthly Mean Water Levels for Upper Kananaskis Lake, 1969 - 1980	251
5.2a	Monthly Mean Streamflow in Kananaskis River Below Lower Kananaskis Lake, 1975 - 1980	264
5.2b	1969 - 1980 Alberta Interconnected System Demand and Generating Capacity	266
5.2c	1969 - 1980 Mean Monthly Water Levels for Upper and Lower Kananaskis Lakes and Barrier Reservoir	267
5.2d	Approved Total Installed Generating Capacity for Alberta, 1980 - 1988	271
5.2e	Comparison of Average Daily Flow and Calculated Tennant Flows Required for Fish Habitat in the Kananaskis River	279
5.2f	Comparison of Actual Mean Daily Flows (1978 - 1980) in Kananaskis with Recommended Tennant Flows for Fish Habitat	281
5.2g	1977 Dry Year Flow in Bow River and Minimum Instream Water Quality Requirement	293
5.3a	Probable Snow Management Sites in the Alpine Zone of the Kananaskis District	304
5.3b	Estimated Water Diversion and Consumptive Use by Irrigation Districts in the Bow River Basin	324
5.3c	Zoning Relationships of Lake Levels and Streamflow	339

Chapter 1

1.0 INTRODUCTION

1.1 PROBLEM DEFINITION

1.1.1 General Perspective

Water produced in the Eastern Slopes of southwestern Alberta is perhaps the most important resource of the region. This was officially recognized in 1947 when the Governments of Canada and Alberta jointly established the Eastern Rockies Forest Conservation Board to administer the Forest Reserves of the mountain and foothill regions for watershed improvement. The governing Act described the management objective as being one of:

> "...obtaining the greatest possible flow in the Saskatchewan River and its tributaries." (Hanson, 1973)

While this did much to bring attention to the importance of the Eastern Slopes as a water supply region, the unfortunate choice of wording has led to several problems. Chief among the problems is that water yield increases have been emphasized as the dominant and sometimes sole objective of research into watershed management in the Eastern Slopes (Laycock, 1973). This is unrealistic for the following reasons:

a) it fails to recognize that other objectives for watershed management may be more viable, such as regime modification, flood protection and reduction, erosion and sedimentation limitation, and stream and streamside habitat improvement.

b) no regional demand studies have been undertaken to establish water supply - water demand relationships, thus it is not reasonable to assume that water yield increases must be stressed in all mountain and foothill regions;

c) the greatest possible yield could be obtained if all the vegetative cover were removed and surfaces were maintained in as bare a condition as possible. However, the conflicts with other land use activities, and the disastrous regime, flooding, erosion and sedimentation, and quality conditions that would result from it, would present far greater problems than are now present.

A regional analysis of the Eastern Slopes would establish the actual and potential water supply - water demand patterns for each drainage basin. More importantly it would delimit those watersheds where other water management objectives including regime improvement, flood limitation, erosion and sedimentation control, and improvement of stream habitat environment are most urgently needed. These and other objectives may be more appropriate for particular watersheds, and while many are complementary in combination, some are not. Defining management objectives before planning is therefore required to reduce the potential for conflicts between competing water and land uses.

Another problem is that watershed management and forest manipulation for water yield increases are common themes in the literature (Sopper & Lull, 1966; Neill, 1977; Swanson, 1977). While this is an extremely narrow view it is nontheless a common one, and is responsible for a large part of the forest hydrology research in the Eastern Slopes. At a recent (1977) symposium of the Alberta Watershed Research Program it was suggested that proven

forest management schemes be used to augment the water supply of the Saskatchewan River system, and if this assurance could not be given then watershed management should be declared irrelevant for water supply purposes (Swanson, 1977). It is unfortunate that so much time and money have been spent in pursuit of one goal, that of water yield increases, while other watershed objectives have been virtually ignored. A close look at streamflow records would reveal that it is not necessarily increased supplies of water that are needed in all areas, but rather it is a more equitable distribution in some seasons that is the real need in most basins. Also, some watersheds through fire damage, overgrazing or logging have been left severely damaged and require restoration along with reduced flooding, erosion and sedimentation limitation and improved water quality (Laycock, 1973).

1.1.2 Water and Resource Planning in the Eastern Slopes

The theme that watershed management and yield improvement are synonomous is promoted in the literature and is proving to be a major limitation in the recognition of other watershed objectives. Studies done for or by government agencies on land use, land allocation and resource potential in the Eastern Slopes have all stressed the importance of the region for water supply. Unfortunately, the usual recommendations are to limit those activities which might interfere with or reduce the flow from the watershed, whether their effects upon regime and other water management objectives were or could be significant.

Increasing demands for use of land and water resources of the Eastern Slopes prompted a number of preliminary planning studies,

the major one being the Foothills Resource Allocation Study. In this study, fifteen land use categories were assessed in an attempt to determine the most beneficial allocation of resources in the Foothills Region (Nowicki, 1972). Using Canada Land Inventory information for available resources, combined with additional resource inventories for other use categories, each use was then rated based on the ability of the land to supply the resource. The study went as far as to suggest that by fitting all of the resource ratings to a standard scale, it would be possible to relate the ratings from inventory to inventory (Nowicki, 1972). However, since no demand studies had been conducted for each category, the selection of land use categories was arbitrary. For example, four wildlife categories were included, while recreation and watershed were undivided. Recreation might well have a dozen or more categories, each with different demand requirements for different activities. In watershed management the regional demands might vary considerably, requiring quite different objectives. Watershed management was given top priority by the Canadian and Alberta Governments in the Eastern Rockies Forest Conservation Acts, yet in the Foothills Resource Allocation Study only 5 percent of the Forest Reserve was rated good or excellent, while 95 percent was given low or moderate rating for this purpose (Laycock, 1973). In the final analysis any form of comparison between categories is difficult since management objectives had not been defined. It should be noted that Phase 1 of four phases planned for the Foothills Resource Allocation Study was completed and that corresponding economic, watershed and other studies which were started were left incomplete. Thus, the balance of information on resources was never attained subjecting the study and application process to suspected bias.

The existence of such a study and reliance upon it by planners and the public for information preparatory to the finalization of a comprehensive land use plan can have serious implications for present and future users. In 1977 the Alberta Government published its "Policy for Resource Management in the Eastern Slopes", a policy that embodies a zoning concept as a means of implementing land use plans. The policy as stated is that the management emphasis is on the maintenance of normal streamflow and quality, with the main objective being watershed protection (Alberta Energy and Natural Resources, 1977). Since watershed protection cannot be satisfied by establishing a separate zone, it is implicit in the policy that any and all land use activities will be assessed for regional compatibility. Although it was recognized that water yield, regime, and quality could be increased, altered and improved, no consideration is given in the policy on how to accommodate these or other objectives which may be regionally more appropriate than simple protection.

1.1.3 Need for a Regional Analysis

It is quite apparent that while watershed management is considered a high priority in the Eastern Slopes, it is doubtful that anything more than a protection of present streamflow conditions is envisioned. This is due, in part, to the lack of relevent watershed information. Since regional analyses have not been conducted for the Eastern Slopes, there is no way of telling where regime conditions can or should be improved, or whether yield increases are necessary, desireable or even achievable. It is important to identify those watersheds where erosion control and sedimentation limitation can enhance water quality. It is

equally important to understand that enhancement of the stream environment may be advantageous for fish and wildlife, recreational and downstream users. For too long watershed management of the headwaters areas has been oriented towards maintaining existing flow quality, quantity and timing. However, this approach does not address the problems and conflicts created by changes in water supply and demand patterns. What is required is a detailed watershed analysis on a region by region basis, including information on the water supply and demand patterns and how each can be influenced by management decisions.

As a basis for presenting a detailed watershed analysis, a study area was selected that is large enough to represent a distinct region for planning purposes. The Kananaskis District is a 940 sq. km (360 sq. mi.) watershed located in the southern portion of the Front Ranges of the Eastern Slopes. Its geographic location, situated as it is between, and to the south of the route between, Banff and Calgary, and its bountiful supply of water, wildlife and scenic resources has led to increasing user pressures on the area. Recent developments, especially the creation of Kananaskis Provincial Park and Kananaskis Country, suggest that watershed objectives have again been ignored, and that the management strategy will be one of fostering a wilderness experience by protecting existing natural processes. There is a major problem with this strategy; however, since much of the watershed is controlled, using reservoirs, for hydro-electric purposes by TransAlta Utilities (formerly Calgary Power Ltd.) a private utility company. Conflicts may arise between the Province, Alberta Recreation and Parks, and TransAlta Utilities due to different management priorities. Concerns have already been expressed that the hydro peaking operation is affecting fish production in the rivers and is preventing the full realization of the recreational and aesthetic use potential of the lakes and rivers (Alberta Energy and Natural Resources, 1980). A better understanding of the water

resources of the District, including natural and modified runoff and water supply patterns, may help in developing alternative strategies in watershed management for land and resource planning in the District. The following section is a more detailed outline of the objectives and procedures to be used in this study.

1.2 STUDY OBJECTIVE AND PROCEDURES

1.2.1 Study Objective

A number of problem areas were mentioned in the previous section concerning land use activities, the development of zoning and use categories, and the limitations in data systems employing watershed information for planning purposes. Although these problems are apparent in the planning and management proposed for the Kananaskis District, they are only unique in this area in their emphasis and orientation, simply because for any basin the water supply and demand patterns are unique. Effectively translating watershed concerns into the planning process has not been successful, largely because of the traditional approach which considers the watershed as having one function, that of supplying a high yield of water. To correct this approach, a methodology is required which allows for a comprehensive examination of a wide range of watershed objectives, and consideration of possible management alternatives. Ideally, the methodology employed in this study is designed for maximum flexibility, and the procedures outlined can be used in any regional analysis.

The overall study objective is to develop and apply a methodology in which current management demands are examined, the physical basin and water supply characteristics are analysed, and water management alternatives for the Kananaskis District are suggested.

The methodology is a modified form of a regional analysis as described by Wilm and Dunford (1941), and as demonstrated in the Eastern Slopes by Laycock (1957a). Essentially, the methodology consists of three components: examination of current demand patterns and management structures, analysis of physical hydro-meteorological characteristics and water supply patterns, and suggestions and alternatives for water management based on the demand - supply analysis.

The assessment of management demands requires an in-depth examination of literature and other data sources. As a result, this discussion is aptly suited for inclusion in the general review of the literature in Chapter 2. This will help provide a clear perspective of the existing management structure, and establish a rational basis for discussion of physical watershed patterns and potential water management objectives.

The analysis of the physical watershed characteristics will be concentrated on two main areas of the hydrologic cycle. A detailed examination of the major climatic patterns, and the intra-regional climatic elements and in addition, a similar analysis of the complete water supply system will constitute the bulk of the physical data to be used later in the management alternatives assessment.

The culmination of the regional analysis is the assessment of water management alternatives, attuned to the physical realities of the Kananaskis District. Such an analysis will illucidate the viability of various water management objectives for hydrologically unique areas within the District, and highlight the advantages and limitations of potential water and land uses in these areas.

There are then, essentially three components which require study and elaboration and the following brief discussion is an outline of the general nature of each component.

1.2.2 Assessment of Management Demands

The present state of demands on the land and water resources of the Kananaskis District will undoubtably influence any future management decisions. Alternatives in water management will be affected by current on-site and downstream demands and potential forecast demands. For example, the on-site demands for hydro-electric power and recreation may be in conflict. Also the proportion of Kananaskis water which is now utilized downstream for irrigation, municipal and industrial needs will ultimately increase. The potential for conflicts looms large between both on-site and downstream users. The potential for improvements to the water resource system, including increases in water yield (if any), changes in regime, reductions in flooding and sedimentation of the water supply, and changes to the lakes and streamside environments need to be examined as management objectives. While some objectives may prove beneficial in alleviating conflicts between users, others may not be compatible or desirable for today's user orientations.

It is important to recognize that significant changes in user orientations of the land and water resources have occurred over the last several decades. Therefore flexibility in management of these resources will enable future generations to accommodate new and changing demand patterns. The policies by which the Provincial government administers the Kananaskis District are determined to a great extent by external factors, and the consequences of this will be examined with respect to potential

alternatives for water management.

1.2.3 Physical - Climatic Analysis

This component is a detailed analysis of the physical watershed characteristics. It will be used to help explain, in part, how the physiographic expressions of the region influence the climatic and water balance patterns which are so fundamental in any watershed study. In the Kananaskis District, as in any other mountainous region, structural characteristics such as elevation, orientation of ridges and proximity to major relief features, will each have an influence on wind and air mass movements, temperature regimen and precipitation patterns. Other physiographic features such as rock type and surficial geology influence the hydrology of the region by providing variation in retention and detention storage (depending on material type) and ultimately affect snowmelt and runoff rates and recharge to streams. The literature will be used to profile techniques used elsewhere in developing the watershed relationships noted above, and detailed mapping of the physiographic patterns will help explain some of these relationships in the Kananaskis District.

The most important physical characteristics of the watershed which must be evaluated are the climatic patterns. Thorough knowledge of the major air mass systems and their characteristics will help explain the variations noted for particular elements, notably precipitation and evapotranspiration. With precipitation more must be known than just totals, since it is the spatial and temporal characteristics which may be influential in management decision making and ultimately the allocation of land uses. Of interest here are the intra-regional variations in precipitation

type and amount on a seasonal basis, the accuracy of existing measurement situations, the probability for the return of expected and extreme events, and methods of best illustrating this information for planning purposes. Use of the literature and conventional data sources will be of some help, and other methods of procuring and analysing data as suggested by Bruce and Clark (1966), Gray (1970), Laycock (1978), Linsley et al (1949) and others, will be investigated. It is difficult to assess the importance of evapotranspiration on the water balance of the mountainous region, especially since estimates in the literature are highly variable and subject to considerable debate. However, an attempt will be made to describe the patterns of evapotranspiration and the effects of Chinook winds on a seasonal and locational basis, using research results and water budget estimates.

1.2.4 Water Supply Analysis

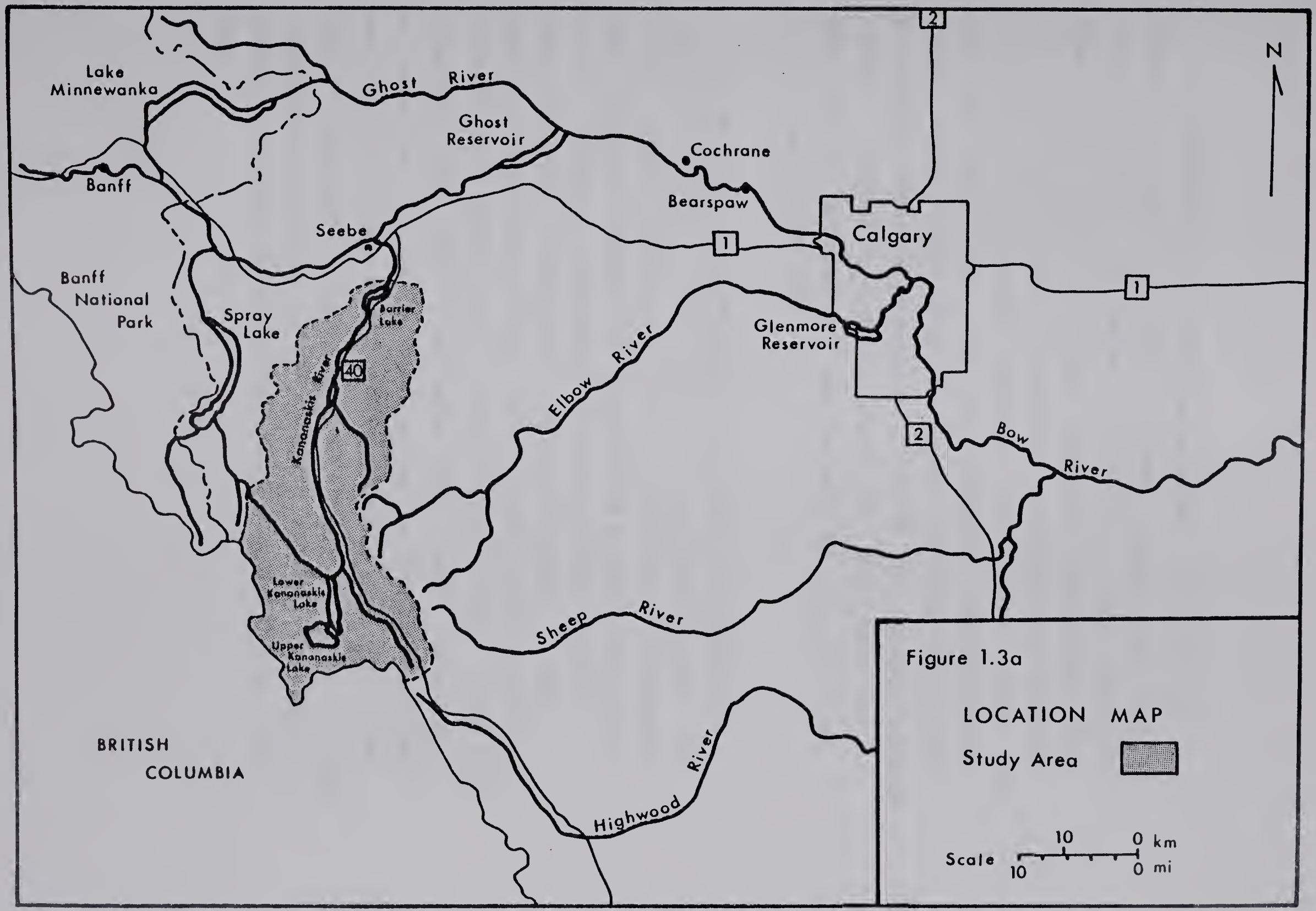
The third component of the study requires the determination of actual water supply patterns. This involves the use of water balance computations and other statistical techniques in revealing the intra-regional differences in runoff and water yield in the District. Recorded data sources will be used to help with identification of the spatial and temporal patterns of lake levels and streamflows. Personal observations and literature sources will be used to explain how changing management priorities have led to a change in water supply characteristics.

1.3 THE STUDY AREA

1.3.1 Geographic Perspective

The Kananaskis District is situated within the Bow Forest Reserve of the Eastern Slopes, approximately 75 km (46.5 miles) west of the city of Calgary, Alberta. The boundaries of the area under study are virtually the same as the natural watershed divides of the Kananaskis River and its tributaries with one small exception. The study boundary is delimited along the south and south-west by the Continenetal Divide and Banff National Park. The eastern and western boundaries follow the natural divides which separate the Kananaskis District from the Elbow River basin to the east, and the Spray River district to the west. The northern boundary approximates an east-west line running to the north of Barrier Lake (see Figure 1.3a). This purposely excludes the downstream sections of the Kananaskis River, which traverses the Bow Valley for approximately 9.0 km. (5.6 miles) before joining the Bow River, since this area is physiographically and hydrologically indistinguishable from the Bow Valley (Osborn and Jackson, 1974).

The resultant study area takes in approximately 940 sq. km. (360 sq. miles). This coincides with the derived watershed area value used by Calgary Power Ltd., for its stage-discharge calculations, and reported by the Water Survey of Canada in the Historical Streamflow Summary for 1978. On the survey grid of Alberta, this area encompasses parts of Townships 18 through 24, and Ranges 8 to 10 west of the 5th meridian.


Lake Minnewanka
Ghost River
Ghost Reservoir
Cochrane
Banff
Bearspaw
Seebe
Calgary
Banff National Park
Spray Lake
Barrier Lake
Kananaskis River
40
Glenmore Reservoir
Elbow River
Bow River
Lower Kananaskis Lake
Upper Kananaskis Lake
Sheep River
Highwood River
BRITISH COLUMBIA
N
Figure 1.3a
LOCATION MAP
Study Area
Scale
10 0 km
10 0 mi

As a portion of the Bow River watershed, the Kananaskis District is readily accessible to Alberta residents and out-of province visitors. The region is less than an hour's drive west from Calgary, a rapidly expanding metropolis now numbering over half a million residents, along either the Trans-Canada Highway or Highway 1A. The travel efficiency of the highway network, combined with the presence of the trans-continental Canadian Pacific Railway mainline, associates this segment of the Bow Valley with a nationally important transportation route. The recently improved section of Highway 40 (formerly the Forestry Trunk Road) has meant improved accessibility into the more remote upland areas of the Kananaskis District.

As an aid in describing major locations and features the reader is advised to obtain several of the following maps. For a broad regional perspective the NTS 1:250,000 scale Kananaskis Lakes (82J) and Calgary (820) maps provide a good areal picture of the locational, physiographic and geo-political features associated with a large part of the Eastern Slopes. A more detailed perspective of relief, drainage and cultural features of the Kananaskis District can be obtained from the NTS 1:50,000 scale Kananaskis Lakes (82J/11) and Exshaw (820/3) maps. Several maps of vegetation, geology, surficial geology and soils are available and portions of these will be reproduced where applicable. New maps of Kananaskis Provincial Park and Kananaskis Country are being produced for Alberta Recreation and Parks, and as these become available they will supplement the topographic and thematic data base.

1.3.2 Physiography

The Kananaskis District is situated wholly within the Front Ranges of the Rocky Mountains. Like most mountain landscapes, the District owes its topographic form to the interaction of endogenic forces that have uplifted the land, and exogenic forces that are wearing it down. Between 60 and 100 million years ago (Late Cretaceous to Early Tertiary on the geologic time scale) the Rocky Mountains were created by the thrusting of sheets of rock to the east (Osborn and Jackson, 1974). Thus a huge anticline, whose apex lies along the Continental Divide was formed. Subsequent down-faulting of several rock units resulted in a very rugged character which has since undergone further alteration due to glacial and post-glacial erosion. In general the major ridges are fault blocks or anticlines consisting of resistant Paleozoic carbonates. Conversely, most valleys occupy the down-faulted and synclinal belts underlain by the softer Mesozoic shales and sandstones. Over thrusting to the east is apparent, since most ridges tend to have steeper east-facing slopes. Most major fault lines and the strike of most of the folds have a NNW-SSE trend, thus the major subsequent valleys also have this orientation.

Notwithstanding the structural influence on the landscape, much of the present physiographic expression in the Kananaskis District is the result of Pleistocene glaciation. Alpine glaciers moved down from the Divide areas, flowing along the down faulted synclines, carving broad U-shaped valleys. As the glaciers spilled out into the Foothills, less erosion and more deposition produced large amounts of glacial debris (till) and water-deposited materials were also laid down. Subsequently, the major valleys are broad and flat, generally covered by highly variable depths of

glacial, glacio-fluvial and glacio-lacustrine deposits. The lower slopes are characterized by a thin veneer of glacial till, sometimes overlain by post-glacial talus materials. Upper elevations are generally bare due to precipitously steep slopes and sharp-crested narrow ridges developed during long and intense glacial activity. During deglaciation and even at the present time, peri-glacial frost action on the higher slopes has resulted in strong mass movements of bedrock and surface materials to lower slopes and valley bottoms.

Deposition associated with glacial and post-glacial processes has produced distinctive surface features in the valleys of the Kananaskis District. Kame deposits have been identified in the hilly area surrounding the University of Calgary's Kananaskis Center for Environmental Research, east of Barrier Lake (Osborn and Jackson, 1974). Terraces underlain by outwash occur in the Kananaskis River Valley near the confluence with Ribbon Creek, and Walker (1971) has suggested that terraces on the north-east slope of Barrier Mtn., are remnants of a former pro-glacial lake.

The most prominent non-glacial features to be found in the lower slope and valley bottoms are alluvial fans. Many large alluvial fans can be found at the mouths of tributaries to the Kananaskis River. An excellent example is the fan which juts into Barrier Lake from the east side of Mount Lorette. The fan surfaces are generally steep when underlain by sand or silt (Osborn and Jackson, 1974). Some fans are being incised by streams whereas others are aggrading and enlarging (Stalker, 1973).

The Kananaskis District as a whole is quite rugged with few large flat areas of land. The only significant flat areas in the District are those associated with the main river valley in the vicinity of Pocaterra, Ribbon, Evans-Thomas and Wasootch Creeks. The largest area is located adjacent to Lower Kananaskis Lake, where the gently rolling topography measures between 2.5 km. and 4.0 km. (1.5 and 2.5 miles) wide.

As in any mountainous area, the Kananaskis District is characterized by extremes in elevation. The main Kananaskis valley varies from just over 1350 M. a.s.l. (4430 ft. a.s.l.) at the north end of the study area near the Lusk Creek confluence, to approximately 1675 M. a.s.l. (5500 ft. a.s.l.) in the flat area adjacent to Lower Kananaskis Lake. Changes in relief occur more rapidly away from the main river valley, with abrupt increases of 1000 M. (3281 ft.) over a few kilometres not uncommon. Elevations of the main mountain ranges increase south from the Bow Valley and west towards the Divide. The Opal, Fisher and Elk Ranges have several peaks over 2750 M. a.s.l. (9000 ft. a.s.l.) while the Spray and Kananaskis Ranges have peaks which reach over 2900 M. a.s.l. (9500 ft. a.s.l.). The highest elevations occur along the Continental Divide, the south west boundary of the study area. Here, both Mt. Joffre and Mt. Sir Douglas exceed 3350 M a.s.l. (11,000 ft. a.s.l.). The area elevation (hyposometric) curves depicted in Figure 1.3b, can be used to determine the area above any elevation, and in fact the steepness of the curve reflects the rugged relief in two distinct hydrologic zones (sub-basins) in the District. It is along the Divide where several small glaciers and permanent snowfields can be found clinging to the north and north-east facing slopes. The Mangin Glacier is the largest, extending down the north slope of Mr. Joffre almost 900 M. to an elevation of 2440 M. a.s.l. (8000 ft. a.s.l.). All the glaciers

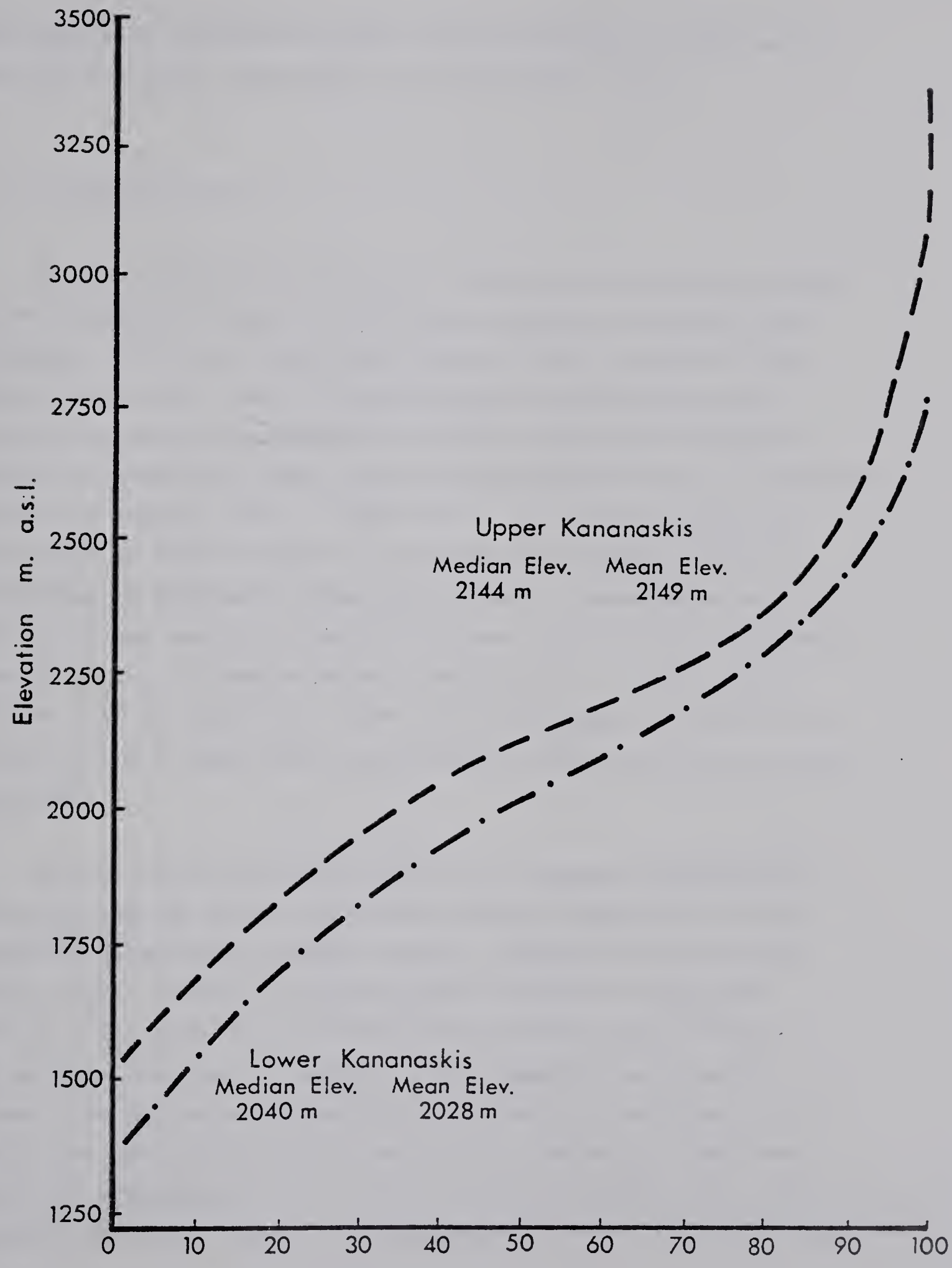


Figure 1.3b Percent of Area Below Indicated Elevation.

and snowfields contribute runoff into the Kananaskis Lakes and as such are important components in the hydrologic cycle.

1.3.3 Bedrock Geology

The best published information sources on the bedrock geology of the Kananaskis District include the articles by Halliday and Mathewson (1971), and Osborn and Jackson (1974), and it is from these sources that much of the following discussion is based. Ancillary sources of information include older maps by Marshall (1922) and Crockford (1949), and doctoral dissertations by Bielenstein (1969) and Jackson (1977). The interest in bedrock geology in this study is the influence of intergranular porosity and rock fracturing on groundwater flow and storage. Considerable work on this topic has been performed by Stevenson (1967, 1974, n.d.) and a summary of his findings appears in Section 4.1. In this brief outline only the major rock types, their lithology, structure and orientation and significant hydro-geologic characteristics will be discussed.

Bedrock in the Kananaskis District is composed generally of two basic ages of rocks, each having several formations or rock groups of successively younger origin. Paleozoic rocks are the oldest rocks, ranging in age from Middle Cambrian (about 530 million years ago) to the Permian-Pennsylvanian period (about 300 million years ago). Mesozoic rocks range in age from the Triassic period (about 225 million years ago) to the Late Cretaceous (about 100 million years ago). The ages, formational units and lithologies of the rocks are given in Table 1.3a. For the most part, the rocks of the Kananaskis District are sedimentary

TABLE 1.3a

Rock Units and Lithologies in the Kananaskis District

GEOLOGIC ERA	AGE/FORMATION OR GROUP	LITHOLOGY
	Cretaceous	
	Belly River FM.	SS, Shaly SS
	Wapiabi FM.	Shale, SS
	Cardium FM.	SS
	Blackstone FM.	Shale, SS
	Blairmore GP	SS, Conglomerate
Mesozoic	Cretaceous - Jurassic	
	Kootenay FM.	SS, Shale, Conglomerate, Coal
	Jurassic	
	Fernie GP.	Shale
	Triassic	
	Spray River GP.	SS, Shaly SS
	Permian - Pennsylvanian	
	Rocky Mtn. GP.	Quartzite, Dolomite, Breccia
	Mississippian	
	Rundle GP.	LMS, Dolomite
	Banff FM.	LMS, Limy SS
Paleozoic		
	Devonian	
	Palliser FM.	Dolomite
	Fairholme GP.	Dolomite, LMS
	Cambrian	
	Pika FM.	LMS, Dolomite
	Eldon FM	LMS, Dolomite

SS - Sandstone
LMS - Limestone

Source: Halliday and Mathewson, 1971

and thus are products of marine deposition originally deposited in horizontal layers. During the formation of the Rocky Mountains, the layers were pushed eastward, resulting in a series of thrust sheets striking NNW-SSE and dipping WSW. The overlapping nature of the thrust sheets causes repetition of outcrops of various sedimentary units with the District (Osborn and Jackson, 1974).

The Paleozoic dolomites $CaMg(CO_3)_2$ and limestone $CaCO3$ generally underlie the major mountain ranges. Consisting mainly of carbonate which is highly resistant to erosion, the dolomites and limestones of the Rundle Group and Banff and Palliser Formations, are the most prominent cliff-forming units. Good exposures of these rocks occur on the slopes of Mt. Kidd and Mt. Lorette among other places (Osborn and Jackson, 1974).

The Mesozoic rocks are mainly clastic in nature and are not as resistant as the carbonates. Generally these rocks consist mainly of shaly or conglomeratic sandstone and are commonly found underlying valley locations. Halliday and Mathewson (1971) identified three broad bands of these rocks trending in a NNW-SSE direction in the study area, one passing beneath Lower Kananaskis Lake, one beneath Mt. Allan, and the third beneath Barrier Lake. The various rock units and their distinctive structural characteristics are mapped (after Osborn and Jackson, 1974, and Halliday and Mathewson, 1971) in Figure 1.3c.

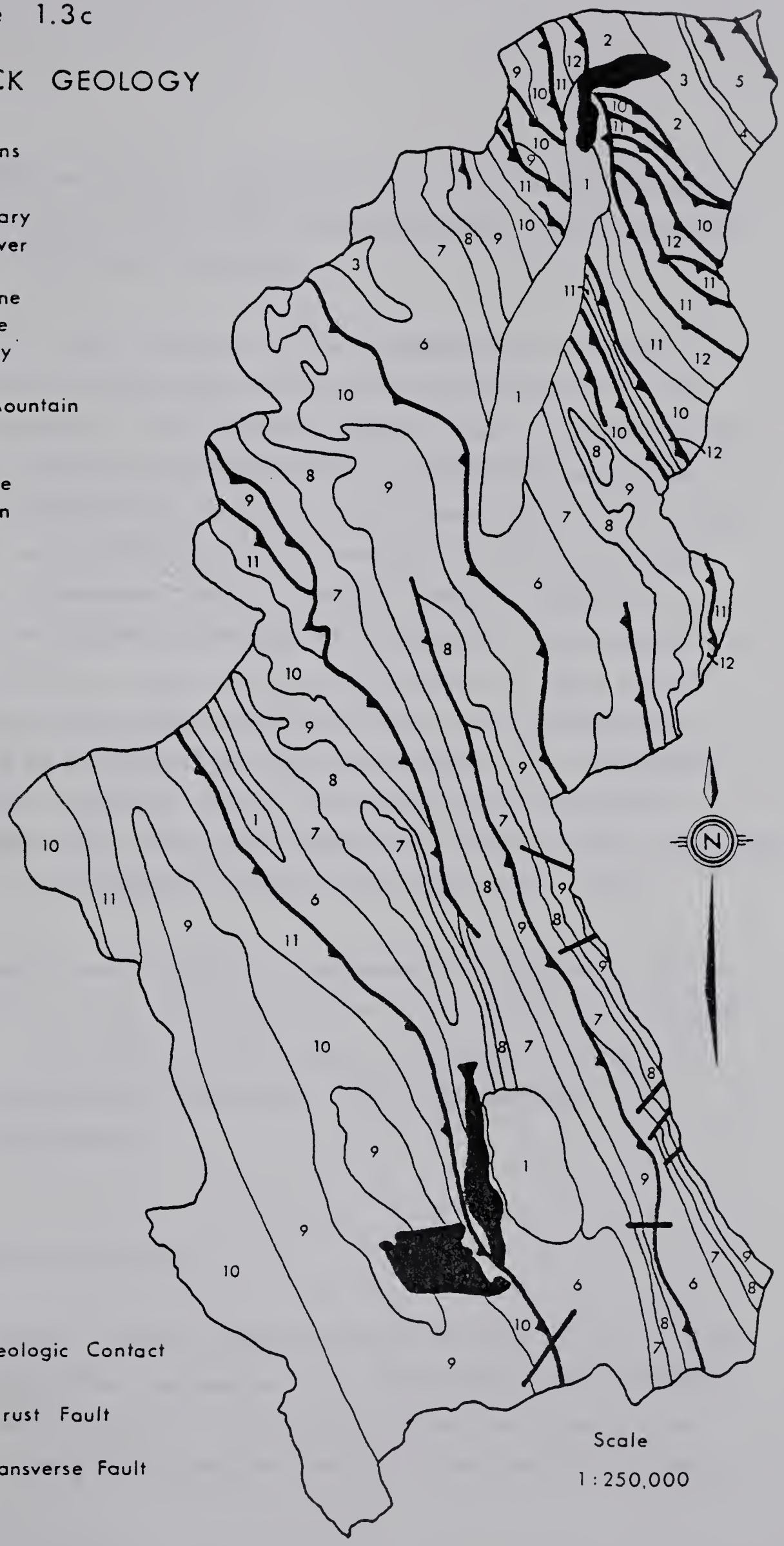
Within the Front Ranges of the Rocky Mountains, several subparallel thrust sheets or fault blocks strike from NNW to SSE. Since each sheet overrides its eastern neighbour, and fault planes generally dip to the WSW, parts of some sheets have become secondarily deformed (Osborn and Jackson, 1974). Depending on the characteristics

Figure 1.3c

BEDROCK GEOLOGY

Formations

1 Quaternary
2 Belly River
3 Cardium
4 Blackstone
5 Blairmore
6 Kootenay
7 Fernie
8 Rocky Mountain
9 Rundle
10 Banff
11 Fairholme
12 Cambrian



(eg. strength) of the rock involved, it is found that Paleozoic rocks are little deformed, while Mesozoic clastic rock are generally highly folded and fractured.

Stevenson (1967, 1974, a.d.) has examined the hydrologic characteristics of the Marmot Creek Experimental Basin in the Kananaskis District. His research suggests that the jointing and small scale fractures associated with the Paleozoic quartzites, dolomites and limestones, close at depth rendering the rock rather impermeable and hydraulically disconnected to the main ground water table (Stevenson, 1967). Mesozoic shales, sandstones and siltstones are generally cemented with negligible intergranular porosity. However, many large scale fractures in these rocks often feature an open space along the fault line, acting much the same way as an hydraulic sink (Stevenson, n.d.). Piezometer tests of these fractured shales, particularly the Fernie and Kootenay Formations, have shown these to be hydraulically connected to the active groundwater reservoir (Stevenson 1967, 1974).

In summary, most storage and movement of groundwater within bedrock occurs in the fractured shales of the Fernie and Kootenay Formations. Conversely, little storage of water occurs in the Paleozoic dolomites and limestones, while the quartzites are generally impermeable.

1.3.4 Surficial Materials

The geologic materials which overlie the bedrock can be described as having two components. To a pedologist, the weathered mantle on the land surface containing mineral and organic components, horizons and properties useful or detrimental to plants,

is termed soil. Soil, in this sense, is classified generally on the basis of horizon characteristics. To an engineer or geologist, soil is an unconsolidated deposit which is classified on the basis of properties that influence strength and behavior (Wagner, 1957). In the latter case, properties such as grain size and water content form the basis of a classification. In mountain watershed regions where most 'developed' soils are intrazonal or azonal, the full depth of loose surface materials over the bedrock may be included in the term soil (Laycock, 1958). Insofar as a traditional pedologic classification tells little about hydrologic properties, the geological approach to soils/surficial materials classification is more useful for watershed investigations.

Even the geological classifications of surficial materials requires amending for watershed purposes, due to the usual practice of describing each deposit based on chronology or morphology. To be useful for land planning, the classification must have relatively few distinct categories so the mapping units will be large, and may, in single or in combination, be used as management units (Laycock, 1958). Combining many of the morphological or chronological units according to similar watershed characteristics will provide the regional perspective a watershed manager needs for making planning decisions. The procedures used to develop such a classification, and the inherent characteristics of each category will be explained more fully in Chapter 2. It is appropriate at this time only to describe materials as they have been mapped in the conventional manner, in order to complement the discussion of the physical characteristics of the Kananaskis District. To avoid confusion in use of nomenclature, the terms surficial materials or surficial deposits will be used to describe the parent material overlying the bedrock.

The principal reference used to describe the surficial materials in the Kananaskis District is Osborn and Jackson, (1974). This is supplemented by Jackson (1977), Stalker (1973), and Bayrock and Reimchen (1977) where necessary. The general descriptions of some of the main terrain units within the District are described further in Table 1.3b, and a detailed depiction of these deposits is given in Figure 1.3d.

Osborn and Jackson (1974) divided the surficial deposits of the District into two parts; those of glacial origin and those of post-glacial origin. Deposits of glacial origin included glacial lake deposits, ice-contact and non ice-contact glacio-fluvial deposits and ground moraine deposits.

Glacial lake deposits are locally common throughout the valley bottoms where streams were ponded by glacial ice. The lake deposits are generally thickly bedded and range from silty clays to fine sands (Osborn and Jackson, 1974). The most extensive area of lake deposits is located immediately around Barrier Lake. Stalker (1973) found that the lake deposits in the Barrier Lake area are up to 24 metres (80 feet) thick.

Ice-contact glacial-fluvial deposits were laid down, either in small hills and depressions, or long sinuous ridges and are referred to respectively as kames, and eskers. These deposits consist of poorly sorted sands and gravels in the case of kames and kettles, and moderately well sorted sands and gravels in the case of eskers. These features vary up to 10 metres (30 feet) in thickness, and are found extensively in the Lusk Creek Valley and north-east of the confluence of Evans-Thomas Creek and the Kananaskis River (Osborn and Jackson, 1974).

TABLE 1.3b

Surficial Materials and Terrain Units in the Kananaskis District as Mapped by Osborn and Jackson (1974)

MAP SYMBOL	NAME	TOPOGRAPHIC FORM	THICKNESS	TEXTURAL DESCRIPTION
1	Stream Deposits	Flood Plain	Variable, less than a metre to tens of metres	Mod.to well sorted sands and gravels with some silt
1a	Older Stream Deposits	Terrace	As above	As above
2	Marsh	Flat surface or shallow depression	Variable, probably increases with increasing area of deposits	Fine sand, silt and clay and organic material
3	Alluvial Fan Deposits	Alluvial Fan	Tens of metres	Decreases in coarseness with distance from poorly sorted silt sand and gravel to silt
3a	Older Alluvial Fan Deposits	Inclined Terrace	As above	As above
4	Rockslide Deposits	Hummocky, Irregular ground	Tens of metres	Angular, very coarse, bouldery rubble
5	Talus	Slopes or cones with average inclinations of 28^{o}-33^{o}, rocky mantle over bedrock	Zero to tens of metres	Angular, bouldery rubble

TABLE 1.3b Cont'd.

MAP SYMBOL	NAME	TOPOGRAPHIC FORM	THICKNESS	TEXTURAL DESCRIPTION
5a	Rock Glacier	Lobate, tongue-like deposit with steep sides and front and concentric wrinkles on surface	Tens of metres	None to angular bouldery rubble
6	Colluvium (Undifferentiated)	As above	Usually less than several metres	Highly variable
6a	Colluvium (Thin over bedrock)	As above	Locally discontinuous to several metres in thickness	As above
6b	Colluvium (Eroded phase)	Closely spaced ravines	Several to tens of metres	As above
6c	Colluvium (Avalanche modified)	Patches of 6, 6a or 6b intermixed with avalanche chutes and debris of talas slopes	Highly variable	As above
7	Glacial Ice	Glacier	Tens to hundreds of metres	N.A.
8	Glacial Lake Deposits	Deposits mantle underlying topography where thin eroded into rolling hills where thick	Up to 24 metres	Fine sand, silt and clay

TABLE 1.3b Cont'd.

MAP SYMBOL	NAME	TOPOGRAPHIC FORM	THICKNESS	TEXTURAL DESCRIPTION
9	Glacio-fluvial Deposits (non-ice contact)	Level or eroded terraces	Tens of metres	Mod. to well sorted sands and gravels
10	Glacial-fluvial Deposits (ice contact)	Hummocky topography sinuous ridges, relief from several to 30 metres	Tens of metres	Mod to poorly sorted sand, silt and gravel, local till
10a	Glacio-fluvial Deposits (ice contact channel modified)	Hummocky to flat, cut by numerous narrow, steep sided marshy valleys	Locally discontinuous over bedrock to tens of metres	As above, with well sorted deposits in meltwater channels
11	Ground Moraine (Smooth topography)	Gently undulating, mirrors underlying topography	Up to 10 metres	Pebble to cobble-sized stones in a sandy, silty, clay matrix
11a	Ground Moraine (Hummocky topography)	Low gentle hummocks	As above	As above
11b	Lateral Moraine	High narrow ridge	Tens of metres	Coarse rock rubble and till
11c	Neo-glacial Moraine	Lateral or ground Moraine	Several to tens of metres	Largely coarse rock rubble

Figure 1.3d

SURFICIAL GEOLOGY

LEGEND

1–7	Post Glacial
8	Glacio–Lacustrine
9–10	Glacio–Fluvial
11	Moraine
R	Bedrock

For Extended Legend See Table 1.3b



(Osborn & Jackson, 1974)

Non ice-contact glacio-fluvial deposits are composed of rounded, moderately to well-sorted sand and gravel deposits which were laid down by flowing water beyond the margin of the retreating glacier. Such deposits are commonly called outwash, and their thicknesses often exceed 30 metres (90 feet). Along Lusk Creek thicknesses up to 66 metres (200 feet) are evident (Stalker, 1973).

Morainal material is composed of till which is defined as a non-sorted, non-stratified sediment carried and deposited by a glacier. Till normally consists of poorly sorted pebble to cobble sized stones in a sandy, silty clay matrix, thus resulting in low percolation rates but high retention of water. Morainal deposits can be found extensively along the valley sides, often in the form of lateral moraines, while large complex drift basins in Marmot Creek, Smith-Dorrien Valley, and especially east of Lower Kananaskis Lake have depths not yet precisely determined.

Deposits of post-glacial origin included in Figure 1.3d and Table 1.3b (Osborn and Jackson, 1974) include stream deposits, marsh deposits, alluvial fan deposits, rockslides, talus and colluvium.

Stream deposits are composed of well to poorly sorted sand and gravel sized particles, and are typically confined to the bottoms of wide valleys in the District. Thicknesses range from less than 1 metre (3 feet) to just over 10 metres (32.8 feet) (Stalker, 1973). The most extensive deposits are found along the Kananaskis River, and the Smith-Dorrien, Evans-Thomas and Pocaterra Creeks (Osborn and Jackson, 1974).

Marsh deposits are characterized by very shallow, or slow-moving stagnant water, or saturated spongy ground, supporting a vegetative cover of hygrophytic grasses, shrubs, slow-moving stagnant water, or saturated spongy ground, supporting a vegetative cover of hygrophytic grasses, shrubs and trees. These sediments are dominated by fine clays and silts but may include large portions of fine sands as well as organic debris. The larger marshes of the District are associated with drainage interruptions precipitated by the disintegration of ice during deglaciation, hence their location east of Lower Kananaskis Lake.

Alluvial fan deposits are accumulations of sediments at the point of emergence of steep gradient streams from mountainous terrain (Bayrock and Reimchen, 1977). Fans are composed of angular to sub-rounded gravel and rubble, thus having a relatively high permeability. Some fans may also contain a high portion of sand or finer materials, thus increasing water retention and fostering a more amenable existence for vegetation growth. Stalker (1973) estimated the thickness of some fans to be over 30 metres (98.4 feet) near their apexes.

Rockslide deposits are accumulations of angular, fractured bedrock fragments which have slipped off generally steeply dipping slopes. Given a large porosity, retention and detention storage is minimal to non-existant in what is considered a generally unstable deposit. The most extensive rockslide apparent in the Kananaskis District is found on the northwest side of Upper Kananaskis Lake. Here, slabs of limestone have fallen away from the steep slope of Mt. Indefatigable to form a haphazard melange of broken rock greater than 10 metres (32.8 feet) in thickness and covering an area estimated at 3.3 sq. km. (1.3 sq. mi.).

Talus deposits, or talus cones, are formed by the loosening and detachment of bedrock fragments along joints and cracks, by frost action and other weathering phenomenon, and then transported by gravity downslope. Talus slopes are distinctive by their slope angles, almost always averaging between 28 and 32 degrees, and by their gradation in sediment size from fine sands and gravels near the top to very coarse angular fragments at the bottom.

The most laterally extensive deposit in the Kananaskis District is colluvium. Colluvium is defined as soil and rock creep material found on slope segments, and it may be derived from other surficial deposits such as till. Thicknesses are variable, being thin at high elevations on steep, long slopes (Bayrock and Reimchin, 1977). High porosity ensures some detention storage of water, but little retention storage occurs in these deposits.

Other features which occupy terrain but do not come under the above classes are glacial ice and bare rock areas. Bare rock areas are fairly extensive at higher elevations along the major ridges but can also be found exposed in valley bottoms. Glacial ice is found only at higher elevations along the Continental Divide. Both of these terrain units are included in the map. Since both are important in influencing the runoff component of the hydrologic cycle, they will be dealt with in more detail in Chapter 2.

1.3.5 Drainage Characteristics

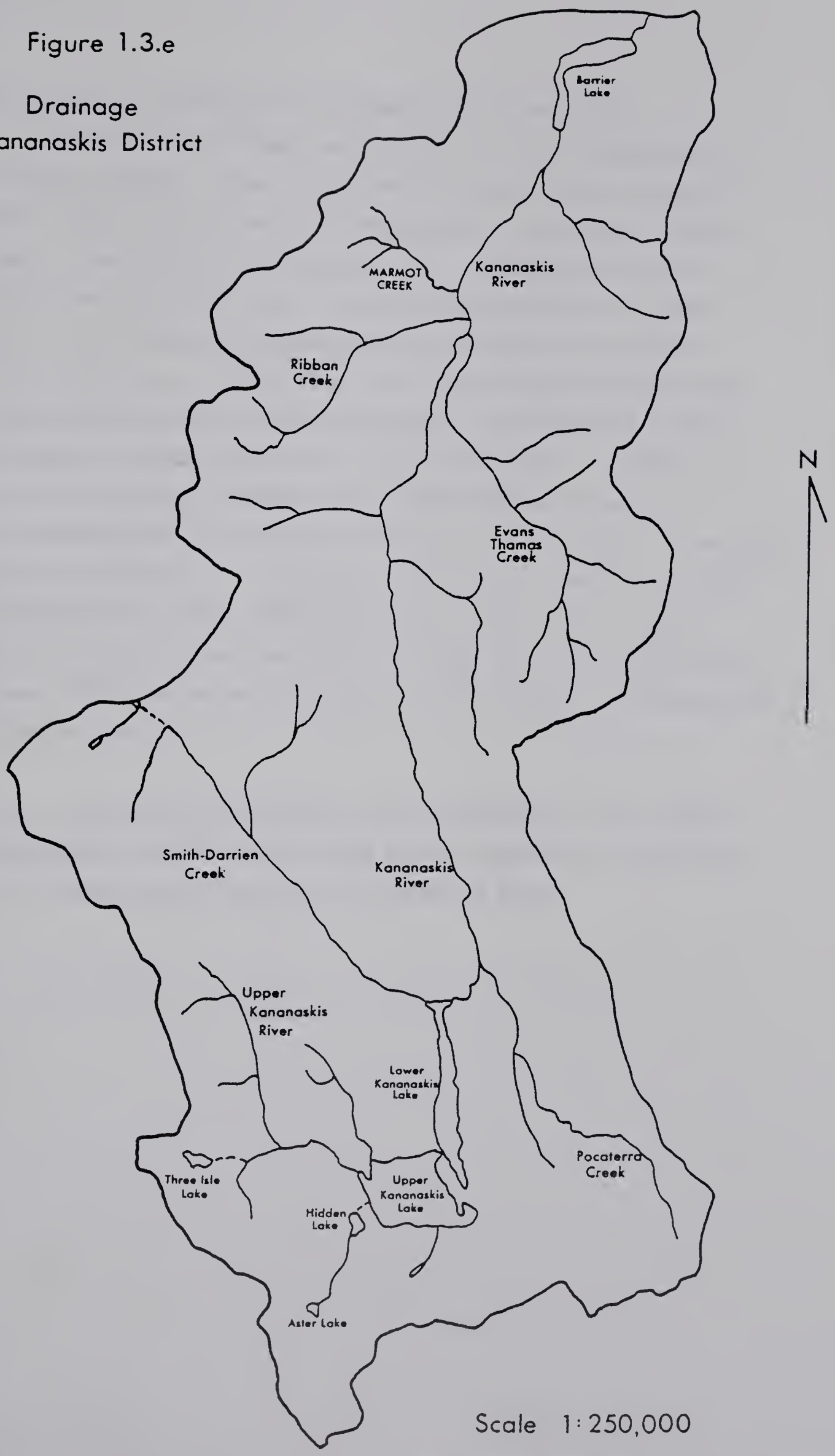
The surface water system in the Kananaskis District consists of the Kananaskis River, several major tributaries, numerous minor tributaries and several lakes. The largest lakes are those which have been increased in size or created through structural modification. This includes Upper and Lower Kananaskis Lakes, which have been enlarged and Barrier Lake which is completely artificial. Several streams, including Burstall Creek, French Creek and Kent Creek, have had their courses modified by TransAlta Utilities, while some stretches of the Kananaskis River have been channelized and straightened to reduce flood hazards. The drainage network depicted in Figure 1.3e includes only the major lakes and tributaries of the Kananaskis River.

Given the Kananaskis District's rather linear shape, it is not surprising that drainage patterns also exhibit this tendency. The linear drainage patterns are due, in large part, to the structural control which the NNW-SSE trending mountain ranges exert. Thus, most of the major tributaries including Smith-Dorrien Creek, Pocaterra Creek, Evans-Thomas Creek, the Upper Kananaskis River and the stretch of the Kananaskis River south of the Galatea Creek confluence follow this structural control. North of the Galatea Creek confluence the Kananaskis River changes direction, heading north-east, crossing over the resistant Paleozoic formation between Mount Kidd and The Wedge.

Many streams, including the Kananaskis River owe their existence to snow and glacial meltwaters. Since these sources are generally found at high elevation, stream gradients tend to be quite steep. As an example, the area above Upper Kananaskis Lake, as characterized by the profile of the Upper Kananaskis River, has a slope approximately 81 metres per kilometre (430 feet/mile). In contrast the main stream segment of the Kananaskis River below Lower Kananaskis Lake has

Figure 1.3.e

Drainage
Kananaskis District

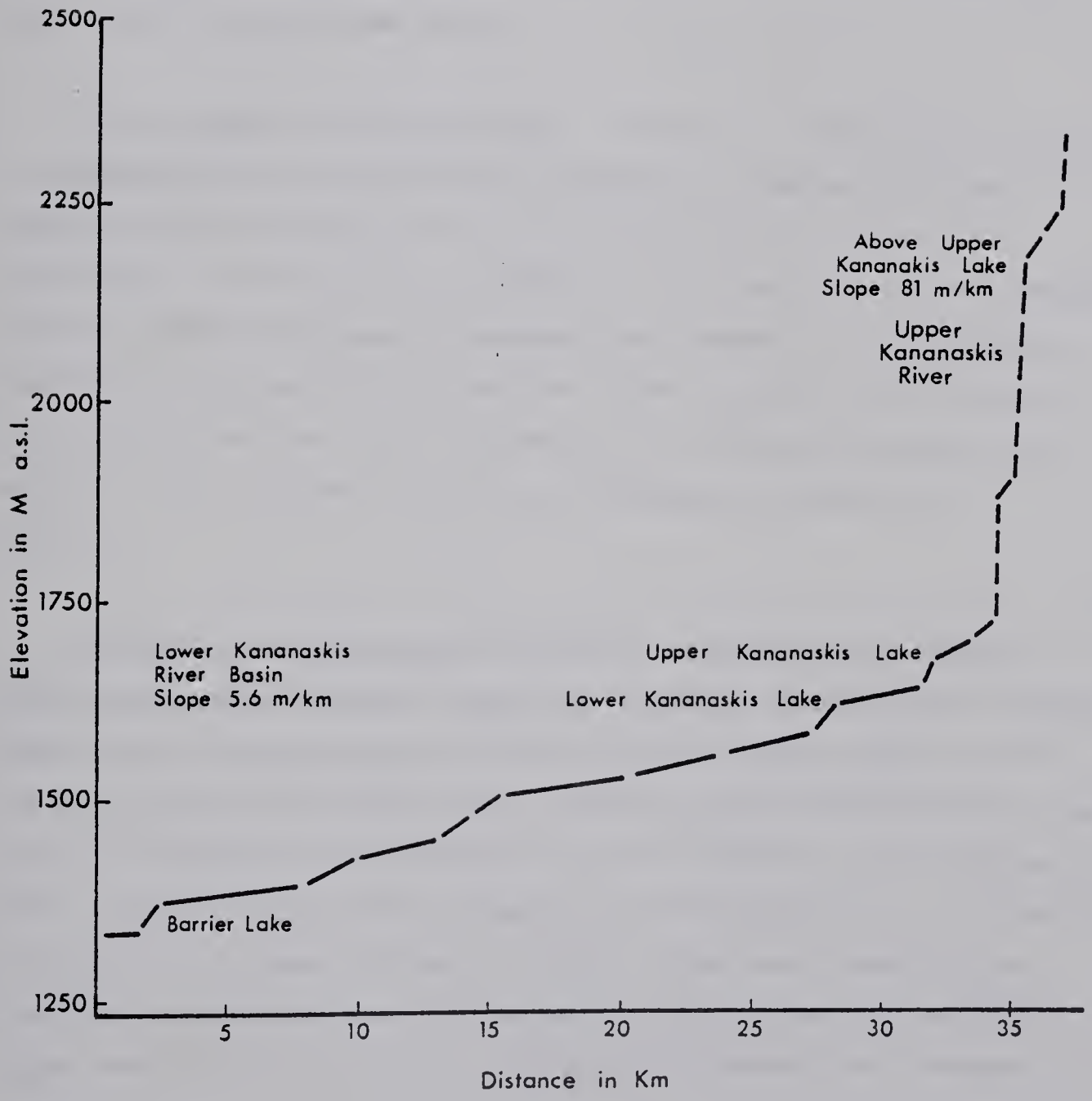


a slope of about 5.6 metres per kilometre (30 feet/mile). Figure 1.3f depicts the stream profile for the main Kananaskis River drainage system. Most of the major streams are perennial in nature, that is they flow even during low flow periods (like fall) due to contributions from base flow. Streams which are intermittent usually lack soil and surficial material storage. Therefore, many streams at higher and intermediate elevations, from 2745 metres a.s.l. (7000 feet a.s.l.) are dry between rains after the snowmelt period. This situation is documented in the stream gauging records compiled by the Water Survey of Canada for the upper slope areas of Marmot Creek Experimental Watershed. Personal observations attest to its occurrence in similar situations throughout the District. It has been calculated (Eastern Rockies Forest Conservation Board, 1967) that only 180 km (111 miles) of perennial channel exist during an average year in the District, while almost 10 times as much, 1700 km (1000 miles) of intermittent channel can be found.

Since a detailed examination of the hydrology of the basin, including runoff, stramflow and lake level patterns is covered in Chapter 4, these details will not be repeated here.

Figure 1.3f

STREAM PROFILE



1.3.6 Climate

Several authors have discussed the influence of major locational controls on the climate of the Eastern Slopes including Laycock, 1957a, 1957b; Longley, 1967a; Lester, 1974; Janz and Storr, 1977; Powell, 1977; and others. Since a major component of this study is an in-depth analysis of climatic patterns and their relationship with watershed patterns, only a brief overview of the major climatic controls, generalized climatic features, and characteristics of the available data base will be dealt with here.

The climate of the Kananskis District is determined largely by geographical position and topographical characteristics. Geographical position implies consideration of latitude, continental location, the proximity of the Rocky Mountain complex, and the characteristics of dominant air masses. Physiographic characteristics such as elevation, slope, aspect and others are responsible for the local variations in climate throughout the region. All of these factors are discussed in detail in Chapter 3.

Generally the Kananaskis District experiences definite summer and winter seasons separated by short transitional periods. Summers are characterized by warm days with cold nights due to the high elevation of the area. Daytime summer temperatures range from 15.6 degrees C (60 degrees F) to 21 degrees C (70 degrees F), while temperatures in the 4 degrees C (40 degrees F) to 10 degrees C (50 degrees F) range are not uncommon. Maximum temperatures, sometimes reaching above 27 degrees C (80 degrees F), usually occur near the end of July. Differences between the average daily

maximum and minimum temperatures during the summer months can be from 5.5 degrees C (10 degrees F) to 8 degrees C (15 degrees F) between the upper and lower slopes of the valley (Munn and Storr, 1967). On clear summer nights temperature inversions of between 2.7 degrees C (5 degrees F) and 5.5 degrees C (10 degrees F) are usual in the lowest 91.4 metres (300 feet) of the valley MacHattie, 1970).

The winter climate is characterized by alternations of cold, dry periods with periods of comparitively warm, dry windy conditions. This variability arises from frequent injections of cold, arctic air which moves into the District from the prairies to the northeast, and mild Pacific (mP) air from the west. The latter, known as Chinook phenomenon is characterized by warm, dry gusty winds, which occasionally reach gust velocities of 50 metres/sec. (100 mph) (Marsh, 1965). Longley (1967b) has shown these Chinook events to be quite frequent in the Kananaskis District, occuring on average about 29 times between December and February. Mean January temperatures hover around the -9.7 degree C (14 degrees F) level.

Total annual precipitation measures nearly 650 mm. (25 inches) at the Kananaskis Centre for Environmental Research, elevation 1390 metres a.s.l. (4560 feet a.s.l.), opposite Barrier Lake at the north end of the study area. Maximum precipitation occurs between April and September, peaking in June, and is primarily in the form of rainfall in the warmest months on the valley bottoms. Powell (1973) has shown that only about 30 percent of the annual precipitation occurs during the six winter months for the Kananaskis Centre. Snow accounts for only 40 percent of the annual precipitation of 650 mm at the Kananaskis Centre for Environmental Research, and much of this falls in April which is

the highest snowfall month. The true variability of precipitation regimes within the District is exemplified by Storr's (1967) findings in the Marmot Creek research basin where as much as 70 to 75 percent of the annual precipitation received at upper elevations in the valley, between 2135 metres a.s.l. (7000 feet a.s.l.) and 2743 metres a.s.l. (9000 feet a.s.l.) occurs as snow.

Detailed temperature and precipitation variations within the Kananaskis District are not well known, due to relatively few representative meteorological stations and their short term nature. In Chapter 3 all of this data, combined with personal observations, recent publications on climatology in the mountains and new techniques in hydrometeorological mapping (to be discussed in Chapter 2), will be combined with general climatic principles to produce detailed maps of precipitation supplemented by interpretations of snowfall characteristics.

1.3.7 Vegetation

The forest cover of the alpine valleys and lower slopes is made up primarily of conifers. The most common species in the District is lodgepole pine. At higher elevations lodgepole pine is replaced by a mixture of spruce and alpine fir, which in turn gives way to alpine larch and tundra above the timberline. Actual timberline varies from 1830 metres a.s.l. (6000 feet a.s.l.) to 2290 metres a.s.l. (7500 feet a.s.l.)

Spruce-fir forests can also be found in areas of moderate elevation, such as the watershed divides between Pocaterra Creek and the Little Elbow River and the Burstall Lakes divide, where drainage is inhibited by low lying relatively featureless topographical divides. Bog areas are found generally in low to

moderate elevations where groundwater emergence is common. Only on southerly exposed slopes and on the valley bottoms north of the Galatea Creek confluence, can groves of trembling aspen and areas of grassy herbaceous vegetation be found.

As a basis for developing sound forest management practices, all of Alberta's forests have been mapped several times (the most recent initiated in 1972) utilizing a forest cover-type classification. Table 1.3c gives the forest inventory statistics, based on the most recent survey and several publications, for the Kananaskis District. From the table it is evident that just over one-third (38 percent) of the entire District is covered by forest vegetation. The remaining 62 percent includes all bare rock, rocky alpine, sub-alpine and montane meadows, marshes, bogs, water,cleared areas, alienated land and grasslands (Jaques and Legge, 1974). As single species both lodgepole pine and spruce each make up just over 30 percent of total forest cover, but when combined in various dominance and subordinate groupings, these two species account for over 95 percent of total forest cover in the Kananaskis District. It is significant to note that seral forest types occupy at least 69 percent of all forest land in the District, illustrating the importance of past disturbance, especially fires, to the present forest composition. As a basis for presenting a generalized view of vegetation distribution throughout the District, a forest cover type map based on several sources including Alberta Lands and Forests Forest Cover Maps, Duffy and England (1967), Kirby (1973),Jaques and Legge (1974), and including personal observation in the summers of 1978 and 1979 by this author, is depicted in Figure 1.3g.

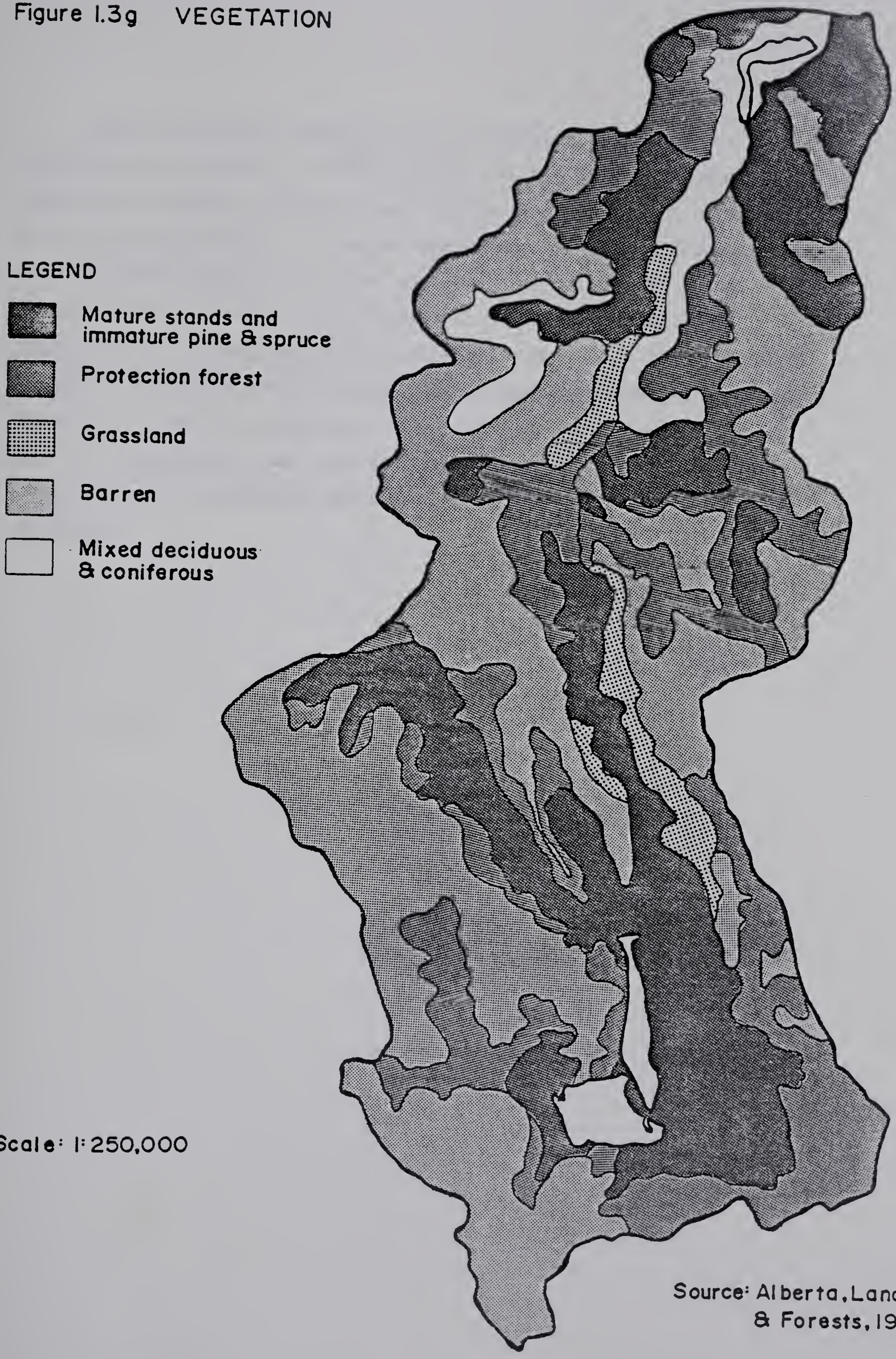
TABLE 1.3c

Total Area of Forest Cover Types in the Kananaskis Valley

COVER TYPE	HECTARES	PERCENTAGE OF TOTAL FOREST COVER	PERCENTAGE OF TOTAL VALLEY AREA
Spruce	10,659	30.2	11.50
Spruce-lodgepole pine	5,956	16.9	6.40
Lodgepole pine/spruce	6,163	17.5	6.60
Lodgepole pine	11,092	31.4	11.90
Lodgepole pine/aspen	179	0.5	0.20
Aspen/lodgepole pine	117	0.3	0.10
Aspen	915	2.6	1.00
Aspen/spruce	85	0.2	0.10
Spruce/aspen	73	0.2	0.10
Aspen/lodgepole pine/spruce	29	0.1	0.05
Lodgepole pine/spruce/aspen	22	0.1	0.05
Totals	11 Types	35,290	38.00

Source: Alberta Forest Service, 1963; and Kirby, C.L. 1973)

Figure 1.3g VEGETATION



Scale: 1:250,000

Source: Alberta, Lands & Forests, 1976

Forest cover-type mapping, while adequate for forest productivity studies, is often inadequate for land and watershed management planning efforts that require more than just information on overstory species. For water management purposes, information on associated land use factors such as water consumption and transpiration patterns and effects on soil moisture storage retention and detention characteristics, can assist the watershed manager in defining areas where vegetation management (ie. thinning, removal or species replacement) could influence water supply and regime conditions. The considerable volume of research results pertaining to vegetation and water management will be reviewed in Chapter 2.

Chapter 2

2.0 LITERATURE REVIEW

2.1 EAST SLOPES PERSPECTIVE

2.1.1 Water Management in the Eastern Slopes

Several agencies have been involved with planning and management of the Eastern Slopes of Alberta in general, and the Kananaskis District in particular. Prior to the 1930 transfer of resources to the Province of Alberta, the National Parks branch of the Dominion Government wielded power over much of the Saskatchewan River headwaters. The boundaries of the National Parks varied considerably during these early years, incorporating at various times all or part of the Kananaskis District (Alberta, Environment Conservation Authority, 1974). The management policies of the National Parks were generally liberal, often encouraging lumbering, mining and grazing (Marsh, 1969). In 1910 the Forest Reserve of the Rocky Mountains was created by the Dominion Government to provide an area outside the National Parks for active resource exploitation, while at the same time managing the forests for future needs (Byrne, 1968). Water management was not an objective of the land management policies of either the Dominion Parks or Dominion Forest departments as evidenced by the widespread fires and virtually uncontrolled resource extraction allowed during these years (Marsh, 1969). With the passage of the National Parks Act in 1930, boundaries of the National Parks were redefined and the

Forest Reserve came under Provincial jurisdiction. The objectives for management remained identical to those formulated under the Dominion Government, although recognition of the need for protection of animals, birds and fish and for the maintenance of conditions favourable to a continuous water supply was espoused (Alberta, Environment Conservation Authority, 1973).

During the 1930s, a period of low rainfall years combined with low streamflow helped to accentuate the importance of the Eastern Slopes as a water supply region. Still, a management policy recognizing water management as an important objective in land use planning was not developed, and continued resource exploitation, in combination with the areally destructive fires of 1936, devastated much of the Bow Forest Reserve (Laycock, 1973). Only after the war years did the Federal and Provincial governments agree to a combined approach to administration and management of the Eastern Slopes.

The Eastern Rockies Forest Conservation Board, established under joint Federal-Provincial legislation in 1947, provided the first general land management policy for the entire Rocky Mountain Forest Reserve (Alberta, Energy and Natural Resources, 1977). The purposes of the Board were to:

1. to construct, operate and maintain, and to supervise the construction, operation and maintenance of projects and facilities required for the conservation of the forests and the protection of the watersheds in the Rocky Mountains Forest Reserve;

2. to protect the forests in the reserve from fire, insects, disease and other damage; and

3. to conserve, develop, maintain and manage the forests in the reserve with a view to obtaining the greatest possible flow of water in the Saskatchewan River and its tributaries.

(Alberta, Environment Conservation Authority, 1974)

The somewhat contradictory statement of objectives for water management has to this day resulted in confusion over how the policy was to be implemented. Protection of forest from fires maintains or stabilizes flow regime conditions due to generally favourable soil moisture storage. The maintenance of a healthy living forest and forest floor litter encourages root penetration and development into the soil, as well as a stable soil surface. A stable soil surface discourages erosion, yet encourages percolation of water into lower levels aided by the rooting network. With improved infiltration characteristics, subsurface and throughflow movements of soil moisture into the riparian and telluric ground-water systems occur. Combined with the increases in evapotranspiration that would occur, the promotion and maintenance of a vibrant forest cover has the effect of decreasing the total water yield while at the same time delaying runoff from individual rainfall and snowmelt events. Obtaining the greatest possible yield or flow could be achieved through large-scale forest removal with all the consequent side effects which this practice delivers, including increased erosion and sedimentation of streams and poor regime conditions. This is not meant to imply that all logging is poorly implemented and has bad effects. Careful harvesting can avoid many of the problems noted above. It is known that the interest in water management and specifically yield improvement was due, in part, to the Prairie Farm Rehabilitation Act and other joint Federal-Provincial involvements in water supply schemes for downstream irrigation (Hanson, 1973).

In its formative years the Board set out to collect information on the hydro-meteorology of the East Slopes through the use of field surveys and instrumentation programs (Laycock, 1957b). Recognizing the Eastern Slopes as a major water producing area, but lacking specific ways to solve problems in management, prompted the Board to request research into possible management techniques. This request led to the creation of the Alberta (East Slopes) Watershed Research Program, formed by Federal-Provincial agreement between 1959 and 1963 (Swanson, 1977). The scope and objectives of the A.W.R.P. were outlined by Jeffrey (1964, 1965, 1967) and can be simply stated as follows:

> "To determine how to manage wild land areas....
> ....for water production and water supply
> protection."

A large part of the research by the A.W.R.P. has been devoted to understanding and describing the hydrology of the Eastern Slopes and a detailed look at this research effort will follow this section.

In 1964 the Province of Alberta passed the Forest Reserve Act formally recognizing the importance of conservation of forests and the maintenance of conditions favourable to optimum water supply (Hanson, 1973). In practice this Act did nothing to promote water management but in fact was used to support the Board's policy of restricting recreational use of large sections of the Reserve (Alberta, Environment Conservation Authority, 1973; Eastern Rockies Forest Conservation Board, 1964).

Due to increasing pressures for water, land and other resource uses in the Eastern Slopes, the Province of Alberta in co-operation with the Lands Directorate of Environment Canada, undertook

a resources study in 1970. Commissioned the "Foothills Resource Allocation Study", the objective was to carry out a land use planning study utilizing the renewable resources capability studies of the Canada Land Inventory (Nowicki, 1972). As a basis for implementing the methodology, the Kananaskis District was chosen as a test site for the system (Alberta, Environment Conservation Authority, 1974). As mentioned in Section 1.1.2, one result of the study was a Resource Capability map which was used to produce a hypothetical management zone map for a preliminary land use plan.

Six types of physical capability data including inventories for agriculture, forestry, recreation, sport fish, ungulates and waterfowl available from Canada Land Inventory, were combined with additional information on watershed and other resources to produce fifteen land use categories. The selection of use categories was arbitrary since demand studies had not been made for some of the inventories, including watershed or recreation (Laycock, 1973). While four wildlife categories were included, recreation and watershed were undivided. Recreation might well have several subcategories based upon different demand requirements, since the optimum areas for skiing, climbing, boating or picnicing are bound to differ. Similarly, in watershed management objectives might include yield improvement, regime improvement, erosion limitation, sediment yield reduction, flood limitation, quality improvement and several others (Laycock, 1973). While some of these objectives are complementary in combination, some are not, therefore the methodology used by the Foothills Resource Allocation Study is clearly deficient for watershed uses.

The results of the Foothills Resource Allocation Study are also questionable, especially in light of the fact that no defined objectives for each use category were stated at the outset of the study (Alberta, Lands and Forests, 1973). In this assessment only 5 percent of the entire Forest Reserve was rated good or excellent for watershed, while 95 percent was given a low or moderate rating. This is despite the fact that the Southern Foothills Region, as outlined in the study, is the major source of water for irrigation, hydro-power, urban, industrial, recreational and other developments of Southern Alberta, providing upwards of 70 percent of the total streamflow (Laycock, 1973).

Also the term 'good watershed condition', as used in the Foothills Resource Allocation Study, is not useful since it was applied to high water yield areas and not to management problem areas. Thus its use as a rating for the Forest Reserve is also misleading (Laycock, 1973). Given that the Canadian and Alberta governments gave watershed management a top priority in the Eastern Rockies Forest Conservation Board Acts, this striking shift in management orientation as suggested by the Foothills Resource Allocation Study is puzzling. The judgements that the highest value use is by ungulates for 70 percent of the region, watershed for 5 percent and recreation for .66 percent, would indicate very subjective assessment biases by the assessing agencies (Laycock, 1973).

In 1973 the provincial advisory committee, the Environment Conservation Authority (in 1978 changed to Environment Council of Alberta) conducted hearings on 'Land Use and Resource Development in the Eastern Slopes', as a first step in developing a management policy for the region. Data from the Foothills Resource Allocation Study were used to provide information bulletins for the public

prior to the hearings. Briefs presented at the hearings strongly emphasized watershed management and public recreation as priorities in an integrated resource policy (Alberta Environment Conservation Authority, 1974). The E.C.A. formulated 232 recommendations and submitted these to the provincial government at the conclusion of the hearings. The government established an Interdepartmental Planning Committee in 1975 to coordinate an integrated resource planning methodology, and by July 1977 the Government of Alberta had its first comprehensive policy for management of the Eastern Slopes (Alberta, Energy and Natural Resources, 1977).

The 'Policy for Resource Management of the Eastern Slopes' utilizes a zoning concept at a regional level to identify broad areas of land for which policies and integrated management objectives are specified (Alberta, Energy and Natural Resources, 1977). In its present form the system consists of three broad land classification zones which designate large areas of land for varying degrees of protection, multiple use management, and resource development. Within the broad zones eight detailed land use zones outline a range of permitted activities (see table 2.1a), in keeping with the priorities and management objectives of the zone (Alberta, Energy and Natural Resources, 1977).

One major limitation of the Policy is that its zoning concept is generally incompatible with watershed management objectives. The policy states that watershed protection is the only objective to be considered within the present framework. The management emphasis is to be on the maintenance of normal streamflow and water quality, with the goal being to ensure a reliable supply of clean water for aquatic habitat and downstream users (Alberta, Energy and Natural Resources, 1977). To achieve this goal, land

TABLE 2.1a

Permitted Activities by Land Use Zones

ZONE	1	2	3	4	5	6	7	8
ACTIVITY	PRIME PROTECTION	CRITICAL WILDLIFE	SPECIAL USE	GENERAL RECREATION	MULTIPLE USE	AGRI-CULTURE	INDUSTRIAL	FACILITY
Non-Mechanical Recreation	/	/	R	/	/	/	R	/
Fishing	/	/	R	/	/	/	R	/
Hunting	/	/	R	R	/	/	R	X
Trails (Non-Motorized)	R	R	R	/	/	/	R	/
Off Highway Vehicle Activity	X	R	R	R	/	/	/	/
Primitive Camping	R	R	R	/	/	/	X	X
Serviced Camping	X	X	R	/	/	R	X	/
Intensive Recreation	R	X	R	/	/	X	X	/
Scientific Study	/	R	R	R	/	/	/	/
Trapping	/	R	R	R	/	/	X	X
Logging	X	R	R	R	/	/	/	X
Cultivation	X	X	R	X	R	/	X	R
Domestic Grazing	X	R	R	X	/	/	X	R

TABLE 2.1a Cont'd.

ZONE / ACTIVITY	1 PRIME PROTECTION	2 CRITICAL WILDLIFE	3 SPECIAL USE	4 GENERAL RECREATION	5 MULTIPLE USE	6 AGRI-CULTURE	7 INDUSTRIAL	8 FACILITY
Petroleum & Natural Gas Exploration & Development	X	R	R	X	/	/	/	R
Mineral Exploration & Development	X	X	R	X	/	/	/	X
Coal Exploration and Development	X	R	R	R	/	/	/	X
Transportation and Utility Corridors	R	R	R	R	/	/	/	/
Commercial Development	X	X	R	R	R	R	X	/
Industrial Development	X	X	R	X	/	R	/	R
Residential	X	X	R	X	R	/	R	/

/ Permitted Uses - Uses that will be allowed under normal guidelines and land use regulations.
X Not Permitted - Uses that are not compatible with the intent or capabilities of a land use zone.
R Restricted - Uses that may be compatible under certain circumstances and stricter than normal controls.

(Source: Alberta, Energy and Natural Resources, 1977)

use practices will be controlled to prevent alteration of present streamflow conditions.

Striving for watershed protection through land use control is tantamount to indirect management of the water resource. It assumes that the current and near-future state of the water resource in the Eastern Slopes is sufficient to meet present demands on the system. Without a detailed assessment of the various water demands both within and downstream of the Eastern Slopes, how can this assumption be verified? The objective of watershed protection implies a lack of flexibility which may hamper consideration of alternatives to meet changing water demand patterns in the future. More importantly, the policy of watershed protection through land use control establishes a precedent, and this will make it very difficult to implement other management objectives, such as regime improvement, where water supply-demand patterns warrant.

In short, watershed objectives have not been fully integrated into the planning process for the Eastern Slopes for several reasons. Resource studies without pre-defined management objectives are characterized by improper and misleading assessment procedures which cannot possibly arrive at objective decisions regarding water management. Various federal and provincial government agencies have viewed the Eastern Slopes as having one purpose, that of supplying a high yield of water, and therefore this has become the management objective most often espoused. Certainly the lack of information on both the variations in physical water supplies and the current and potential demands for different regions in the Eastern Slopes has contributed to this situation. The following section is an examination of the research efforts of the Alberta Watershed Research Program and its contribution to watershed management.

2.1.2 The Alberta (East Slopes) Watershed Research Program

The Alberta Watershed Research Program was established in 1959 to undertake research into water management techniques in the Eastern Slopes. Formed under the auspices of the Eastern Rockies Forest Conservation Board, the role of the A.W.R.P. has been to carry out research into hydrologic matters relating to the East Slopes (Jeffrey, 1964). Several sites respresenting distinct vegetation-hydrologic zones were selected for water yield research including alpine, sub-alpine and montane zones (Swanson, 1977). The original sites for small-basin research into hydrologic problems were located at Marmot Creek in the Kananaskis District, Deer Creek and Streeter Basin. Marmot Creek has been the most extensively studied basin and much of the following discussion will highlight the research associated with this basin. The objectives of the A.W.R.P. were stated originally as:

1. to provide ways of improving the flow quantity, quality and timing from a watershed.

2. to provide a better understanding of hydrologic processes both locally and in the whole East Slopes area.

3. to provide methods of protecting and monitoring the watershed while forest and other resources are being utilized.

4. to provide ways of restoring damaged watersheds

(Jeffrey, 1964)

These objectives have provided the framework which directs the role of the A.W.R.P. even today, long after the agency which helped to establish it for its own purposes, the Eastern Rockies Forest Conservation Board, was dissolved. The initial years of the A.W.R.P. (1959 - 1962) were dominated by organizational aspects, including the establishmnent of steering and technical committees to review and approve research plans (Redmond, 1964). Also at this time two major types of studies were implemented.

The first of these consisted of surveys and inventories, and the compilation and analysis of existing information dealing with the headwaters area as a whole (Jeffrey, 1965a). For example, McKay et al (1963) summarized all available climatic data for the Saskatchewan River headwaters. Most of these data were collected under the auspices of the Eastern Rockies Forest Conservation Board, or for the Prairie Provinces Water Board and these results were initially described by Laycock (1954, 1957b).

The second type of study required the establishment of gauged watersheds. The use of gauged watersheds, usually characterized by small instrumented basins, as a means of establishing hydrologic parameters is a common practice in the United States, U.S.S.R. and other countries. Such basins are maintained for purposive manipulative experimental treatments, seeking to elucidate the relationships between land management and the amount, timing and quality of water yield (Jeffrey, 1964).

Between 1962 and 1964 the Marmot Creek Experimental Watershed was instrumented with precipitation, temperature, evaporation and wind gauges, and the construction of flow weirs and flumes was completed by the summer of 1965 (Jeffrey, 1965a). A total of

27 meteorological sites in the 9.4 sq. km. (3.65 sq. mi.) basin, containing various types of instrumentation, were maintained by the Atmospheric Environment Service (Mann, 1964; Swanson, 1977). The Water Survey of Canada, in conjunction with the Hydrology Branch of the Canadian Forestry Service, has been responsible for the implementation and maintenance of the streamflow data base (Swanson, 1972). Results of the instrumentation programme and analysis of components associated with the overall study objectives have been generally discussed (Jeffrey, 1967; Golding, 1970; Swanson, 1972), and more especially with numerous papers published in various proceedings (Golding, 1974; Swanson, 1977). The following discussion briefly highlights the results of the hydrometeorological components only.

Initial results of the study of total precipitation helped illustrate the spatial and temporal nature of rain and snow (Curry and Mann, 1965; Mann and Storr, 1967; Storr, 1967; Ferguson and Storr, 1969). Total precipitation averaged almost 90 cm. (35 inches), with high elevation areas over 2290 m a.s.l. (7500 sq. ft. a.s.l.) receiving over 127 cm. (50.0 inches). Summer rainfall during the June to September period varied from 40 to 30 percent of total precipitation, decreasing with elevation. Thus snowfall accounted for almost 70 percent of total precipitation at high elevations.

Mean daily discharges and monthly flows have been measured at the main Marmot Creek weir since 1962 (Jeffrey, 1965a). Peak runoff occurs during the month of June with much of the spring and early summer runoff attributable to snowmelt (Davis, 1964; Golding, 1970). Total measured discharge ranges from 45 cm. (18 inches) to 56 cm. (22 inches) with an average discharge of 50.8 cm (20.0 inches) (Golding, 1970).

An annual water balance for Marmot Creek has been calculated (Stevenson, 1967). Utilizing measured parameters for precipitation, streamflow and change in mean groundwater storage, Stevenson calculated the effect of gravity yield on change in groundwater storage, thus providing a rough estimate of evapotranspiration. The net result shows average precipitation of 882.6 mm (34.75 inches), average streamflow at 522.2 mm (20.56 inches), change in mean groundwater storage at 116.0 mm (0.63 inches) and evapotranspiration estimated at 376.4 mm (14.82 inches).

Attempts to delineate the role of evapotranspiration in the water supply system using energy balance formulae (Munn and Storr, 1967; Storr, 1970) produced estimates of approximately 30 cm (11.8 inches) of water loss. This value reflects a loss of about 0.3 area-cm/day (0.12 area-inches/day) for a 100 day growing season, while later studies (Storr, 1970) showed that this value could approach 0.46 area-cm/day (0.18 area-inches/day).

A considerable amount of attention has been given to the question of factors affecting snowfall and snowcover variations (Golding, 1968, 1969, 1970, 1972a, 1972b, 1973, 1974; Golding and Harlan, 1972; Storr, 1970; Storr and Golding, 1974; Swanson, 1970). Researchers have shown that the average amount of snowfall increases with elevation, from 355 cm (140 inches) of snow at 1754 m a.s.l. (5750 ft. a.s.l.) to over 560 cm (236 inches) of snowfall above 2288 m a.s.l. (7500 ft. a.s.l.). Similarly, the snowcover is markedly different with elevation and extremely variable due to vegetative and terrain characteristics. Snow depth variations of from 0 cm to over 300 cm (118 inches) have been measured in the month of May. Golding (1974) found that snow water equivalent increased with elevation at rates of 1.25 cm (0.5 inches) to 3.92 cm (1.5 inches) for every 100 m (328 ft.) increase in elevation.

Snow water equivalent was also found to decrease with increasing slope, and with increases in forest density.

After ten years of monitoring, research, and analysis of large volumes of bio-physical data, Marmot Basin was considered to be calibrated to the statistical level of precision required before testing of management alternatives could be valid. In keeping with the stated objective of finding ways to improve flow quantity, quality and timing from a watershed (Jeffrey, 1964) the A.W.R.P. proposed to simulate a commercial harvest in 1974 to demonstrate the effects of forest management on these variables. Of particular interest was the desire to show that water quality could be protected under the existing commercial harvesting guidelines in the Province of Alberta.

Proceeding on the basis of a large literature base which supports the premise that increases in water yield are predictable depending on the percentage of a forest that is harvested (Wilm and Dunford, 1948; Hibbert, 1967; Hoover, 1969; Hewlett and Hibbert, 1961; Leaf and Brink, 1972; Bethlahmy, 1972; Hewlett and Helvey, 1970; Satterlund and Haupt, 1972; Lynch et al, 1972; and many others) the A.W.R.P. proposed to test this theory on Marmot Creek. Concurrently with the Marmot Creek research study, a similar study of harvesting effects on water yield was being carried out in the foothills near Hinton, Alberta, on the Northwest Pulp and Power Ltd.'s leases. In Marmot Creek the A.W.R.P. proposed to simulate a commercial harvest cut, utilizing patch type clear cuts ranging in size from 0.012 sq. km (0.004 sq. mi.) to 0.053 sq. km (0.02 sq. mi.) (Golding, 1977). In the Northwest Pulp and Power leases, the logged and commercially clear cut basins ranged in size from 7.8 sq. km (3.0 sq. mi.) to 25.9 sq. km (10.0 sq. mi.) (Swanson and Hillman, 1977).

Preliminary results from Marmot Creek showed that water quality did not change during or after road construction or logging. From the intensive snow surveys conducted in the spring it was found that four out of five patch clear cuts accumulated significantly more snow, almost 22 percent more than was predicted if no treatment had taken place (Golding, 1977). Yet data on streamflow for the three years following treatment showed no statistically significant increase in water yield (Neill, 1977). A re-examination of the runoff data for the post-treatment period has indicated a slight increase (approximately 1 to 2 percent) over expected runoff (Neill, 1980), yet it is clear that the short-term effect of the treatment was quite small. This is due to a succession of dry years which depleted soil moisture reserves. Thus any increases in water supply would first be used to replenish soil moisture and any increases in yield would be muted.

In the Hinton study flow data were collected for one year after treatment of eight pairs of basins. Each pair consisted of a logged and an unlogged basin, as similar as possible in all physical aspects. On the average, the partly deforested basins produced 27 percent more water than the forested (Swanson and Hillman, 1977). From a runoff standpoint, the seasonal yield averaged 190 mm (7.48 inches) from the partly deforested basins and 145 mm (5.70 inches) from the uncut basins (Neill, 1980).

The A.W.R.P. is continuing its work in Marmot Creek including testing other types of reforestation on snow collection and snow melt runoff. Also the A.W.R.P. is continuing to seek an applied role in watershed management, such as in the Oldman River Basin where water supply problems are a current issue. The use of forest manipulation for water supply purposes received a negative response from the Oldman River Basin Study Management Committee, after a study of the physical characteristics of the

basin showed that on average, water yield increases would be minor in normal years, and even less in dry years when the water would be most needed (Neill, 1980).

Given the fiscal restraints imposed on the federal forest hydrology research sections of the A.W.R.P., and the recent departures of key senior research scientists associated with this section, federal involvement and direction in programs will probably continue to diminish and provincial government departments will become more involved. A change from the promotional yield-oriented direction of the Eastern Rockies Forest Conservation Board, to one of regionally applied protection, appears reasonable given the Provincial government's desire for an environmentally secure yet high water producing area.

2.2 MANAGEMENT OF THE KANANASKIS DISTRICT

2.2.1 Administration and Water Management

Prior to the 1900s the lands within the boundaries of the Kananaskis District were administered by the Dominion Lands Branch, Department of the Interior in Ottawa (Oltman and Brehaut, 1974). Construction of the C.P.R. had focussed attention on the Kananaskis area, with its bountiful supplies of timber and water needed by the railway construction crews. In order to appraise the timber resources of the region, Ottawa dispatched in 1883 the Dominion Land Surveyor Louis B. Stewart, who proceeded to divide up the Bow, Kananaskis and Smith-Dorrien valleys into five timber berths (Byrne, 1968). The earliest known extraction of lumber by permit from the Kananaskis District occurred between 1883 and 1886 when James Walker of Canmore cut wood to supply both that town and Calgary (Oltman and Brehaut, 1974). There were few guidelines for cutting at this time and certainly no land management policies concerning water, flooding or erosion. In 1886 the Eau Claire and Bow River Lumber Co., established its first lumber camp in the Kananaskis on the present site of the Eau Claire campground, a presence which continued until 1945.

In 1902 the boundaries of Banff National Park were expanded to include all the Kananaskis District, as well as the neighbouring Spray and Canmore areas. The park was enlarged mainly for the purposes of recreation and game protection, but national park status did not preclude land uses such as lumbering and mining until the National Parks Act was passed in 1930 (Calgary Regional Planning Commission, 1973). Although the Department of the

Interior had recognized the need for conservation on non-agricultural public lands, extraction of timber from the Bow, Spray, Kananaskis and other valleys was careless, wasteful and the cause of many major fires (Calgary Regional Planning Commission, 1973). The frequency of the fires seemed to increase, especially when combinations of drought and poorly cleared slash occured, as reported in 1910 (Olmstead, 1974). Earlier (1889) forest fires were said to have changed watershed capacities to the point where severe flooding occured in Calgary (Olmstead, 1974).

In 1911 when the boundary of Banff National Park shifted to exclude the Kananaskis District, administration also shifted to the Rocky Mountain Forest Reserve and the Lands of the Dominion Forestry Branch (Byrne, 1969). The act establishing the Forest Reserve of the Rocky Mountains stated that:

> "the Forest Reserve was established for the maintenance protection and reproduction of timber....the conservation of minerals and the protection of the animals, birds and fish therein, and for the maintenance of conditions favourable to a continuous water supply" (Canada Statutes, 1911)

Conservation of the forests through fire protection and closer scrutiny of timber cutting practices was supposed to help the watersheds, yet in fact little fire suppression could be attempted due to poor access into many parts of the District.

In 1917 the boundary of Banff National Park was again expanded to take in the Kananaskis District as well as the Spray and Canmore areas (Byrne, 1968). As before lumbering and mineral exploration

were not inhibited by National Park status, and Eau Claire Sawmills Co. increased its activity in the Kananaskis by expanding its base of operations in the Eau Claire and Ribbon Creek areas. With the discovery of coal in the Kootenay formation, claims were staked by George Pocaterra in 1909 on Mt. Allan near Ribbon Creek (Oltman and Brehauf, 1974). No actual mining occured at this time.

In 1930 the National Parks Act was passed prohibiting lumbering and mining within the Parks (Byrne, 1968) and the boundary was moved west to exclude the Spray, Kananaskis and Canmore areas. Since lumbering and mining were allowed to continue within the Forest Reserve's jurisdiction, these practices were not affected by the change in administration. Generally, timber extraction practices were still wasteful and often damaging to most watersheds due to scarification and subsequent erosion and sedimentation of streams. The practices, combined with the dry period during the 1930's, helped contribute to some of the disastrous fires which swept the District and much of the Eastern Slopes (Calgary Regional Planning Commission, 1973).

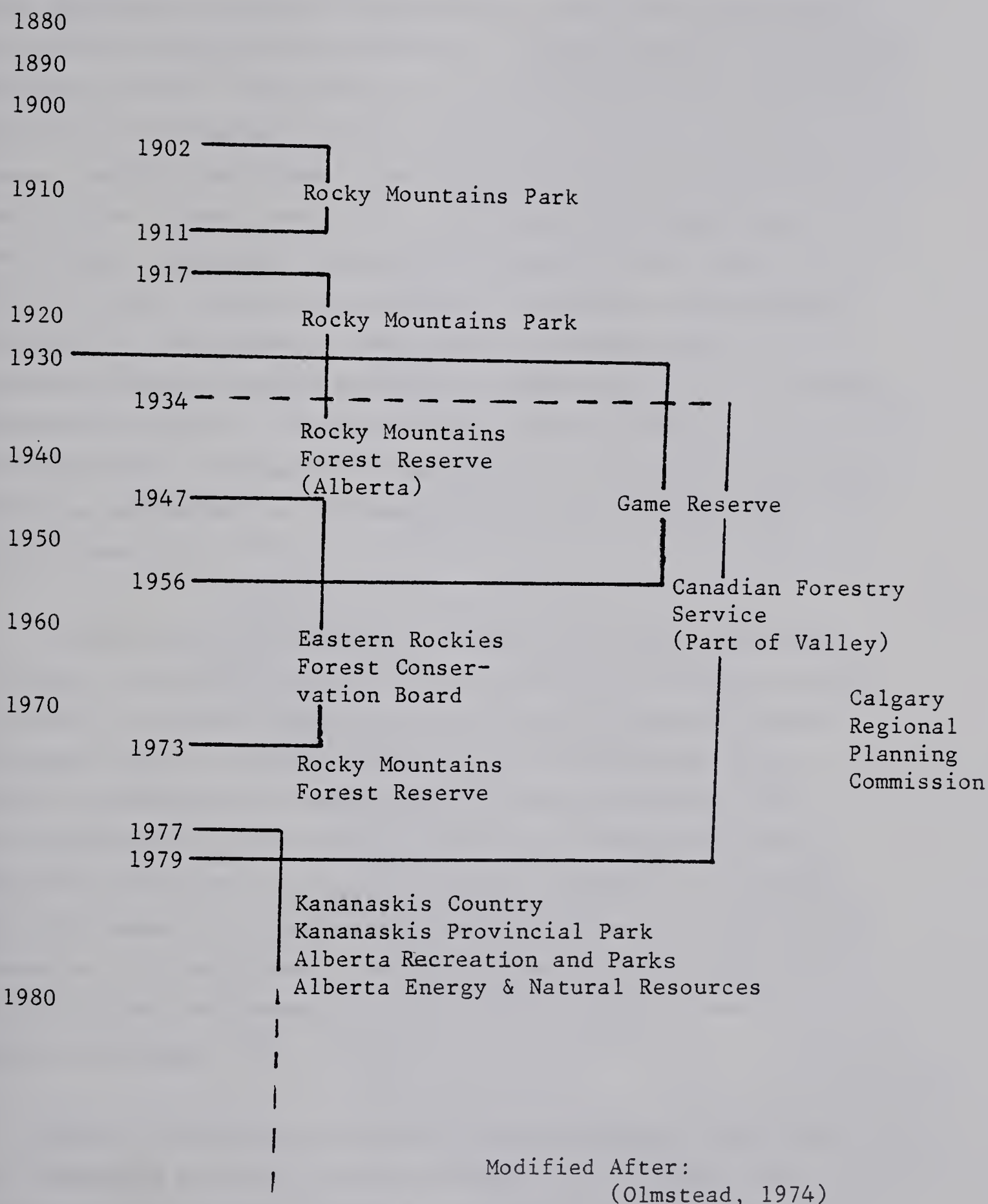
In 1947 the Eastern Rockies Forest Conservation Board inherited the responsibility of administering management policies for the Kananaskis District and the Eastern Slopes. As part of the Board's mandate to protect the forests and preserve natural streamflow conditions, a policy of fire protection was instituted (Hanson, 1973). This involved the development of fire haul roads into remote areas of the Reserve, and the establishment of a fire hazard monitoring system. The subsequent effect of this policy was to foster improved regime conditions, less erosion and sedimentation, and reduced flooding (Laycock, 1973).

Figure 2.2a illustrates the changing administration role in management of the Kananaskis District as presented by Olmstead (1974), modified to reflect changes from 1974 to 1980. One noteworthy absence from the list is perhaps the body which has had the most impact on the District, TransAlta Utilities. While TransAlta Utilities can hardly be thought of as an administrative body, their presence in the District since 1932 has helped to form the prevailing water management structure. Since 1932 when TransAlta Utilities initiated the enlargement of Upper Kananaskis Lake into a reservoir, both the drainage network and the flow regime have been managed to optimize both hydro-electric power production and flow regulation in the Bow River (Calgary Power Ltd., 1973). Examples of land use by TransAlta Utilities include the clearing of forests for construction of power lines, power plants and associated facilities (Jaques and Legge, 1973). Examples of changes to the drainage network include the construction of the three reservoirs, the damming of Mud Lake and the diversion of French Creek, Kent Creek and Pocaterra Creek, as well as a channel diversion of the Kananaskis River (TransAlta Utilities pers. comm., 1978). The flow regime has changed in response to the need for storage for hydro-development and Bow River flow regulation,and as such peak summer flows have been reduced while low winter flows have been augmented (Calgary Power Ltd., 1973). The degree to which flow regime has been altered is discussed in detail in Section 4.3 while the nature of the demand patterns are discussed in Section 2.2.2.

Since September 1977, the responsibility for policy development and land and water management administration has rested with those provincial agencies involved in East Slopes planning, namely Alberta Energy and Natural Resources and Recreation and Parks.

FIGURE 2.2a

Administration of Kananaskis District



Modified After:
(Olmstead, 1974)

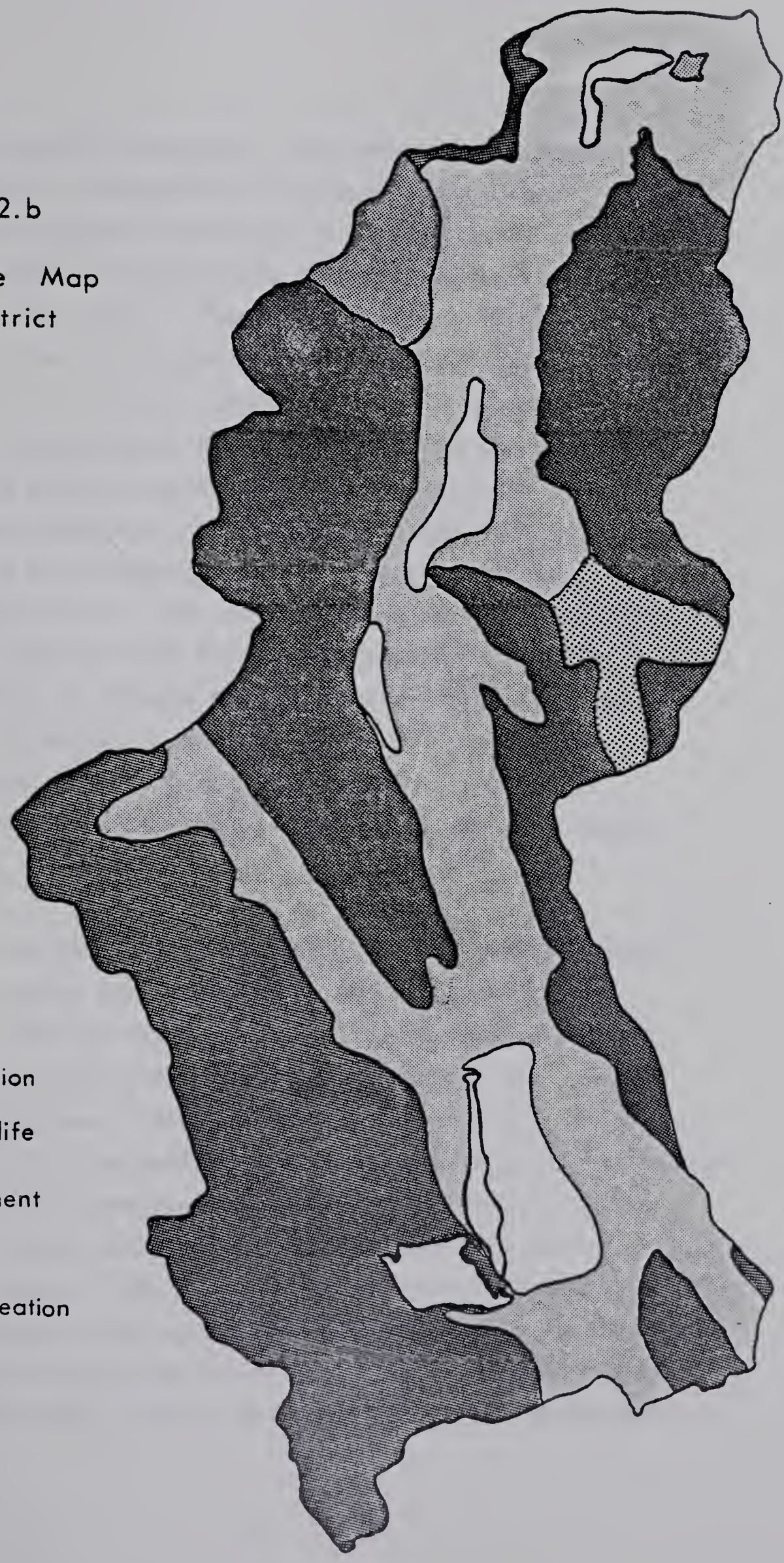
For the Kananaskis District a regional land use zoning system has been employed as a means of implementing the resource management policies of the provincial government (Alberta Engergy and Natural Resources, 1977). The resource zones identified in the Kananaskis District are presented in Figure 2.2b. A total of 5 resource zones, ranging from Prime Protection through Critical Wildlife, Special Use, General Recreation and Facility Development are envisioned. At present, these zones identify broad units of land for which policies and management objectives are specified, including an indication of the types of uses which can be permitted (Alberta Energy and Natural Resources, 1977). Detailed management plans will be prepared for selected areas on a priority basis, particularly when individual projects or developments are conceived for implementation (Alberta Energy and Natural Resources, 1977).

In all zones the management emphasis is on the maintenance of normal streamflow and water quality, with the objective being to ensure a reliable supply of clean water for aquatic habitat (Wyldman, 1977). Land use practices are to be controlled to prevent streamflow from being unduly altered to maintain the self-perpetuating recreational fishery of the Eastern Slopes. Watershed protection is a major emphasis throughout the region, and this cannot be satisfied by establishment of a separate zone. Therefore, all developments will be reviewed for watershed compatibility and environmental impact before being allowed to proceed (Wyldman, 1977).

Within the context of the East Slopes planning principles, and largely as a result of public demand for recreation, the Kananaskis District has become a focal point for the application

Figure 2.2.b

Resource Zone Map
Kananaskis District



of planning for general recreation. The development of the 'Kananaskis Country' recreational concept was given formal recognition by the Alberta government in its 'Policy for Recreation Development of Kananaskis Country' (Alberta, Recreation and Parks, 1977). The establishment of Kananaskis Provincial Park is an indication of the management orientations which are presently in vogue. Kananaskis Country encompasses more than just the Kananaskis District, including the Canmore corridor plus the Elbow-Sheep uplands immediately adjacent to the Fischer and Opal Mts., in the east. Administration for this area was the responsibility of several government departments until March of 1982 at which time it was announced that Kananaskis Country would become an Improvement District administered wholly by Alberta Recreation and Parks effective January 1, 1983 (Alberta, Recreation and Parks, pers. comm., 1982). At the time of this writing, the revised Policy for Recreation Development of Kananaskis Country is awaiting Cabinet approval.

The Policy for Recreation Development of Kananaskis Country contains eleven policy statements which summarize the thrust of the program. None of these eleven policy statements mention water resources, or the role which water management will play in development of this area. The statements of policy do allude to the sensitivity of the environment and the high watershed values as being an important resource. As mentioned in Chapter 1, the 'high watershed value' description refers to the high water yield characteristics of the upper elevation bare rock areas. In most cases, these areas are neither environmentally sensitive nor hydrologically desireable due to the flashy characteristics of the water yield, and they are not subject to cover management.

In discussing the relationship between the Kananaskis Country policy and the East Slopes zoning policy, it was noted that very few non-recreation activities will be permitted to occur. (Alberta Recreation and Parks, 1977). In particular, the Kananaskis Lakes and Barrier Reservoir will continue to operate as storage reservoirs for hydro-power generation (Alberta, Recreation and Parks, 1977). It was stated that since fishing is the only important waterbased recreation activity, the above operations would result in few conflicts (Alberta, Recreation and Parks, 1977). Reservations have been recently expressed (Alberta, Energy and Natural Resources, pers. comm., 1982) that minimal populations of fish are found in the Kananaskis River, and that this is attributable to scouring of spawning beds during high flow periods. Nelson (1965) concluded that the construction of the reservoirs and their subsequent operation for hydro-electric power, changed the physical environment (ie. primarily temperatures and spawning beds) and contributed to observed changes in species composition such as Dolly Varden, cutthroat, brook and rainbow trout, stickleback, lake chub and longnose suckers. The author hastens to add however, that the decrease in game species was largely due to the introduction of new species such as brown trout and white suckers, and sport fishing. In any event, it is difficult to see given the present peaking power mode of operation, how Alberta Recreation and Parks feel that conflicts between TransAlta Utilities operations and water-based recreational activities such as fishing in the Kananaskis River will be few. In the sections to follow, the significance of TransAlta Utilities' operations on recreation and other demand uses will be examined to provide the basis for the discussion of management alternatives in Chapter 5.

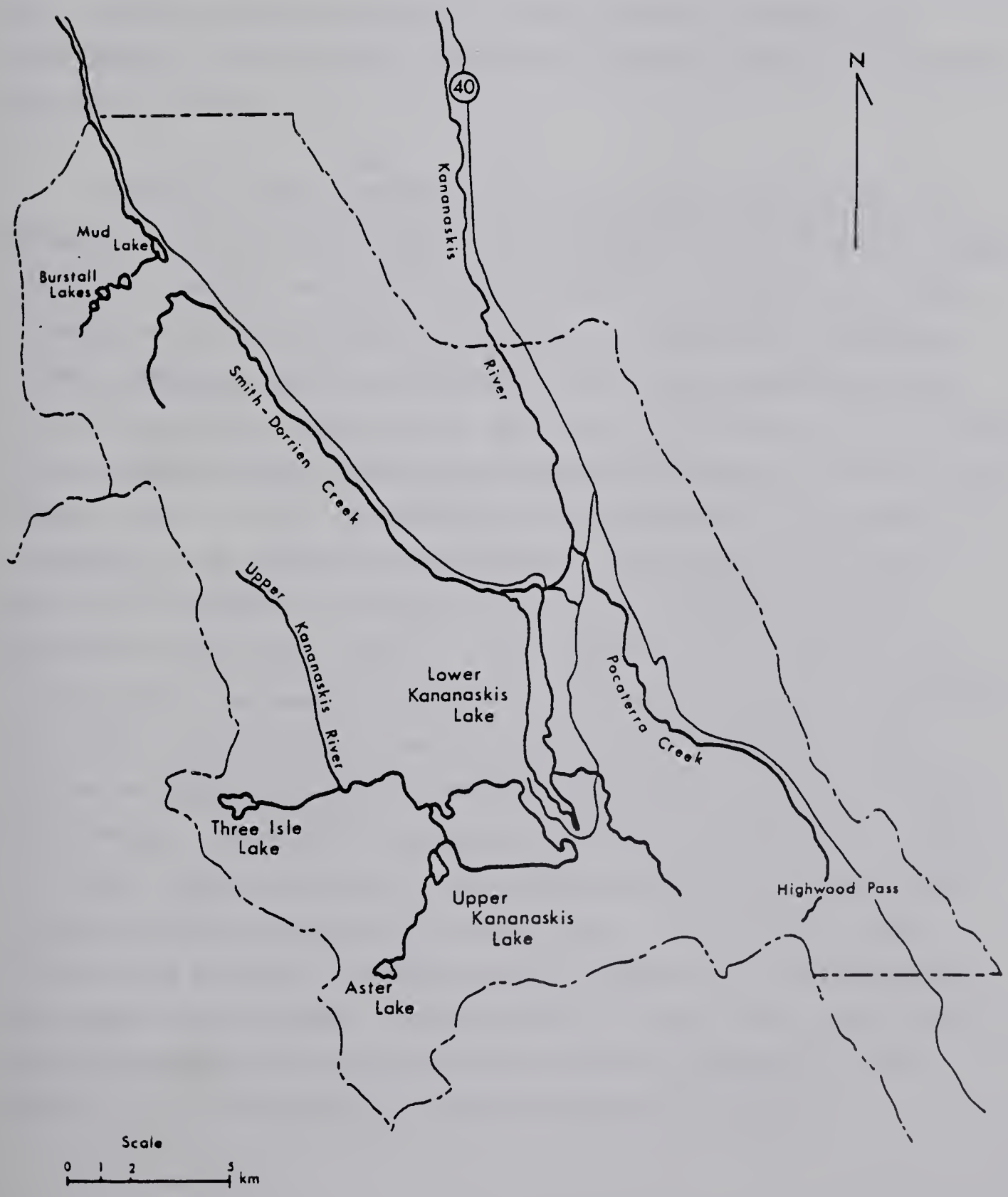
Several nearshore and valley areas will serve as focal points for recreational activiites and services, as discussed in the

policy, presenting unique administrative challenges. A few of the major developments planned and currently underway for Kananaskis Country within the defined study area, as abstracted from the Policy (Alberta, Recreation and Parks, 1977) are described below.

A day-use area which promotes camping as well as fishing and boating is slated for the northern shore of Barrier Lake. A new campground providing a full range of services will be developed at Evans-Thomas bringing the total number of campsites in this area to 150. Adjacent to the campground, a 36 hole tournament level golf course is under development and is scheduled to open in the summer of 1983. The first three alpine villages will be developed, complete with a full range of facilities including chalets, dining areas, swimming pool, tennis courts and picnic areas, at Ribbon Creek, Galatea Creek and in conjuc-tion with the golf course at Evans-Thomas Creek. The Eau-Claire campground is to be expanded to 50 units, with associated hiking trails to tie in with the Fortress Mountain Ski Resort. All future development at Fortress Mountain will be consistent with the Alpine Village concept of providing year-round recreational services so as to improve the economic viability of summer operations. A service centre located at the Fortress Mountain turnoff will serve as the central service facility for the Kananaskis District. Several other recreational developments are proposed in conjuction with Kananaskis Provincial Park and these are discussed separately below.

Kananaskis Provincial Park occupies approximately 508 sq. km (196 sq. mi.) of the southern part of the Kananaskis District (Alberta, Recreation and Parks, 1978) (see Figure 2.2c). Admini-stration of the lands within the Parks boundaries is principally the responsibility of Alberta Recreation and Parks. Priorities

Figure 2.2c KANANASKIS PROVINCIAL PARK



and objectives of land management are centered on providing both primitive day-use and overnight facilities in support of camping and associated recreational activities (Alberta, Recreation and Parks 1978). The overall management policy is one that is compatible with the East Slopes policy, that of providing for orderly growth of a wide range of recreation opportunities while preserving the valuable scenic resources of the area and allowing the development of the natural resources (Alberta, Energy and Natural Resources, 1980).

In concert with the Policy for Recreation Development of Kananaskis Country, but under the auspices of the Provincial Parks Division, several ambitious recreational developments are being undertaken within the Park boundaries. A maximum of 500 auto-access campsites will be provided in the area immediately east of the Kananaskis Lakes and an additional 250 units are to be built in the Smith-Dorrien Valley near Mud Lake (Alberta, Recreation and Parks, 1977). Since the emphasis of recreational development is oriented to the mountain environment, water-based activities, with the exception of fishing, will not be stressed (Alberta Recreation and Parks, 1977). This statement would appear to be at odds with successive government literature (Alberta, Recreation and Parks, 1978) which cites the major lakes and major river system as major attractions for recreationists who enjoy fishing and boating. Even the wording in the Policy equivocates, since it states that boating will be permitted and in fact boat launch ramps are being constructed in the lakes. In addition, fish habitat and stocking programs will be carried out in the lakes and major river system. An indication of the actual water-based demands created by recreational use will be discussed in the section 2.2.2 on Water and Land Use Demand Assessment.

In summary, administration and water management in the Kananaskis District has reflected changing priorities in use patterns. Early agencies such as the Dominion Lands Branch and the Dominion Parks Branch managed the Kananaskis District for its non-renewable resources. Later, provincial ownership did not preclude resource exploitation often at the expense of watershed. Present provincial administration has recognized in policy form the significance of both renewable and non-renewable resources and has implemented management plans which may have an impact on water management. The following section is a discussion of the nature of the current demands on the land and water resources of the District by both TransAlta Utilities, Alberta Recreation and Parks, and downstream interests, and an examination of potential conflicts between current water management strategies and anticipated recreational land and water uses.

2.2.2 Water and Land Use Demand Assessment

Demands for land and water resources in the Kananaskis District are essentially of two types, onsite demands and downstream demands. There is typically an overlapping of the two demands involving water supply and allocation, such as TransAlta Utilities use of Kananaskis water for power production and flow regulation in Bow River hydro-electric plants, but this does not preclude the examination of the two types separately. Onsite demands, particularly those affecting TransAlta Utilities, and Alberta, Recreation and Parks will be discussed first.

TranAlta Utilities initiated its hydro development in the Kananaskis District in 1932-33, raising the level of Upper Kananaskis Lake by 6.1 metres (20 feet) and creating 43,200 dam^3 (35,000 acre-feet) of storage (Calgary Power Ltd., 1973). Within 10 years the Upper Lake was again raised, this time by 15.2 metres (50 feet), thus increasing the amount of storage potential to 123,350 dam^3 (100,000 acre-feet). In 1947 the Barrier Reservoir and power plant were constructed, providing 24,670 dam^3 (20,000 acre-feet) while by 1955 the Pocaterra and Interlakes plants were completed and Lower Kananaskis Lake was enlarged to provide 61,675 dam^3 (50,000 acre-feet) (Calgary Power Ltd. 1973). Since 1955 only minor adjustments to the drainage network including channel straightening and channel diversions (ie. Kent Creek, French Creek, Chester Creek) have been made. Given the usual 'rights of way' associated with hydro-electric plants including power line corridors and tailrace areas, the lands influenced by TransAlta Utilities, are those which border the reservoirs and generally follow the path of the major river. The hydrology of the District is affected to a much greater extent than might be evident, and while a more thorough analysis of the hydrology is included in Chapter 4, some highlights of the water demand patterns will be discussed below.

The existing Water Development Licenses held by TransAlta Utilities Ltd., govern the operations of each hydro plant. Licenses are issued by Alberta Environment for the construction phase of each plant and then reissued for a 10 year developmental period during which plant operations are observed. After the 10 year developmental period, permanent operating licenses are issued by Alberta Environment, yet these licenses only vaguely hint at water management guidelines for plant operations (TransAlta Utilities Ltd., pers. comm., 1982). Restrictions on maximum

allowable water levels in the reservoirs are the only specified water management constraints in each license, and since these maximum limits do not exceed available storage limits there is generally no operational conflict (TransAlta Utilities Ltd., pers. comm., 1982). There are no hard and fast operating rules which govern the disposition of flows or water levels in the Kananaskis District. No operating permits are required for specific management practices, nor is the wording in existing licenses required to change when changes in water management strategies occur, such as moving from load control in the 1950s and 1960s to providing peak load power in the 1970s and 1980s (Alberta Environment pers. comm., 1982).

Despite the fact that many of the operating policies followed by TransAlta Utilities have been agreed to informally, there are specific constraints identified in the Water Power Development Licenses which the Provincial Minister of Environment may invoke if it is deemed necessary. Although many of these constraints are specific to areas outside the Kananaskis District (ie. Ghost Reservoir, Spray River), one constraint in particular could be used to influence Kananaskis operations, as described below:

> The Minister of the Environment can direct that the rate at which water is being impounded in the Bow River Reservoirs be reduced for such periods as to preserve the legal rights granted under the Irrigation Act.
>
> (Dybvig, 1979)

This suggests that downstream irrigation demands may, during low flow/low precipitation years, take precedence over reservoir operation for power production. It also provides a precedent for other interests, either internal or downstream, to seek political assistance in effecting changes to the operation of the Kananaskis

reservoirs. For example, recreation or fisheries interests might wish to see more regular mid-summer flows in the main Kananaskis River and this would be in conflict with current operations which try to hold back as much water as possible for later use in the high energy demand period from October through April. Currently, internal government studies are being conducted as part of the management planning process for Kananaskis Country, to identify policies for the development of outdoor recreation (Alberta, Energy and Natural Resources, 1980). Concerns have been expressed by departmental representatives of the Fish and Wildlife Division of Alberta Energy and Natural Resources and the Provincial Parks and Recreation Development Divisions of Alberta Recreation and Parks, that the operations of the hydroelectric reservoirs in the Kananaskis District are having a negative impact on fish production and the recreation potential of the area (Alberta Energy and Natural Resources, 1980). If the management strategies developed by the Resource Planning Branch of Alberta Energy and Natural Resources should recommend changes to the present methods of operation, and these recommendations are given ministerial approval, then the Water Development Licenses may be reviewed so as to facilitate a more flexible mode of operation which is responsive to recreational and fisheries needs. The recommended management plan is to be completed and implemented by 1983/84, allowing thereafter for a twenty year assessment and review period. The development of tradeoffs or alternative management strategies which may be employed to alleviate the present concerns by certain provincial government agencies over how TransAlta Utilities operates the Kananaskis reservoirs is one of the potential objectives of this thesis.

The water demand patterns of TransAlta Utilities have changed with time in response to changing operational strategies brought about, in part, by the use of thermal power for energy generation. Through its major period of expansion in the 1940s and early 1950s, the Bow River hydro system was the principal supply of electric power to TransAlta Utilities service area. Since peak energy demands occurred during the winter season, storage reservoirs were built to conserve the surplus summer flows to produce power as demanded during the long low water season (Calgary Power Ltd., 1973).

When the first large thermal generating units were added to the system in the late 1950s, these were used to supply a relatively constant load throughout the year because this resulted in maximum use of equipment and the lowest cost of power (Calgary Power Ltd., 1973). To supplement this base load of power from thermal units, the hydro facilities were used to generate power on a seasonal basis, providing only one-quarter of the total power generated by TransAlta Utilities (Calgary Power Ltd., 1973). The last decade has seen the hydro storage operation change again, from that of complementing thermal power generation on a seasonal basis, to that of providing peak load power and supplementing low seasonal in-stream flows in the Bow River.

The hydrologic ramifications of such a strategy on the surface water conditions in the Kananaskis District are apparent from a quick study of the Water Survey of Canada records. The reach of the Kananaskis River downstream of Lower Kananaskis Lake but above Barrier Lake is more relevant to this study, and therefore the Pocaterra flow gauge data will be used to provide flow values.

Data for the years 1975 to 1979 can be used to illustrate the marked seasonal and daily demands on streamflow. Figure 2.2d depicts the variation in seasonal streamflow of the Kananaskis River averaged over a recent period. When compared to the historical values presented and described in Chapter 4.2, the strategy of providing storage of spring runoff for later use is clearly evident. The fact that the bulk of the streamflow is used during winter months to supplement Bow River water levels and peak power loads is a trend that has evolved since thermal power began to assume more of the base power load (Calgary Power Ltd., 1978).

The low volume of streamflow during the summer period is even more demonstrative of the power demand strategy of peaking, as illustrated by the streamflow example in Figure 2.2e. In this example which is typical of most years in the last decade the daily flow variations are extreme. The pattern is developed from twice daily releases of water controlled from the main command centre in Seebe, which determines how much water is needed to supplement Bow River flows or how much is needed to supplement power requirements.

As the discussion in Chapter 4 demonstrates, the area above the Pocaterra gauge generally contributes about 60 percent of the streamflow in the Kananaskis District. Also since most small mountain streams at intermediate and low elevations, experience their peak discharge in June, as discussed in Chapter 4.2, this suggests that the main stream of the Kananaskis River could experience virtually no flow for significant periods during the summer season. The demand for Bow River flow regulation and for peaking power and the operational strategy which achieves this, is responsible for the extreme low summer seasonal flows, and generally unpredictable daily flow variations in the Kananaskis River.

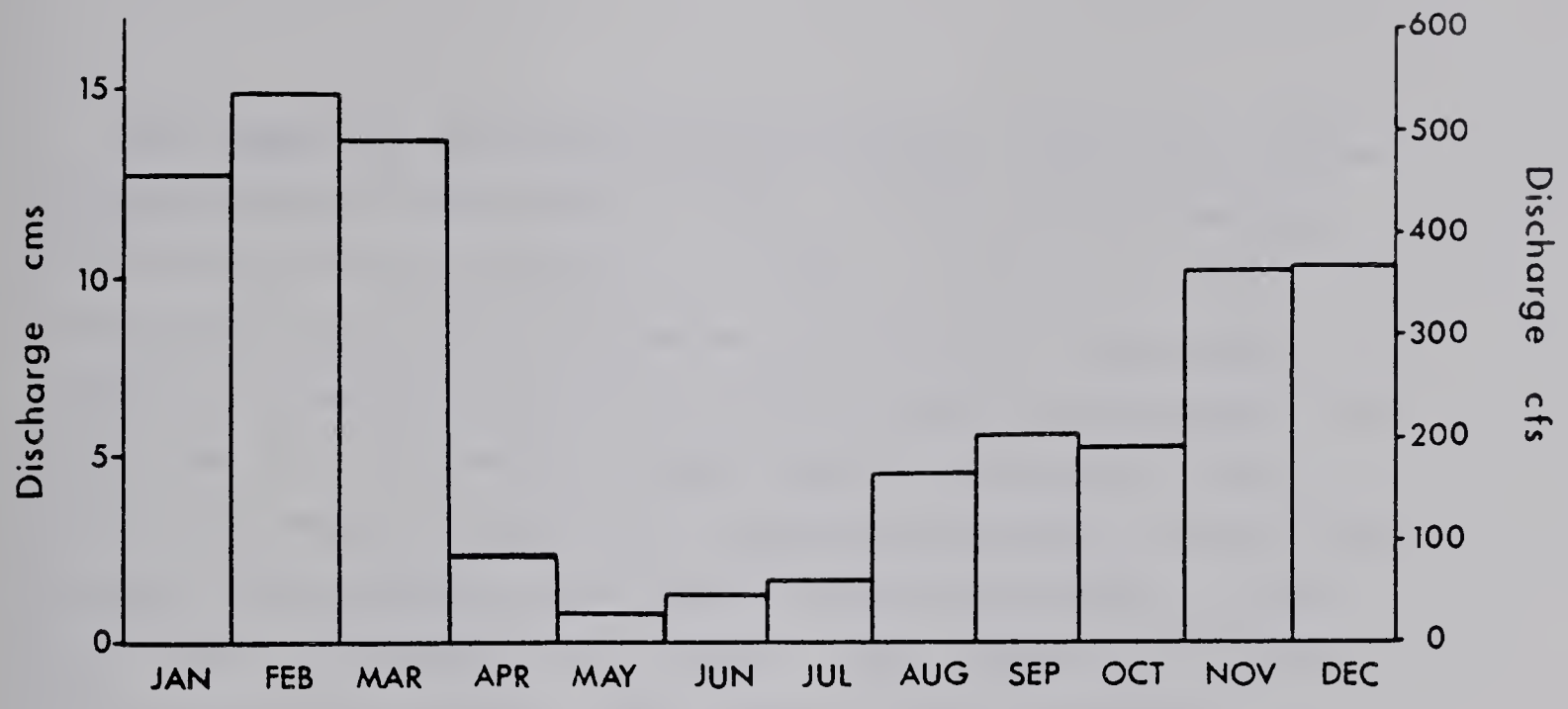


Figure 2.2.d Contemporary Seasonal Streamflow Patterns of Kananaskis River Above Pocaterra Creek 1975 - 79

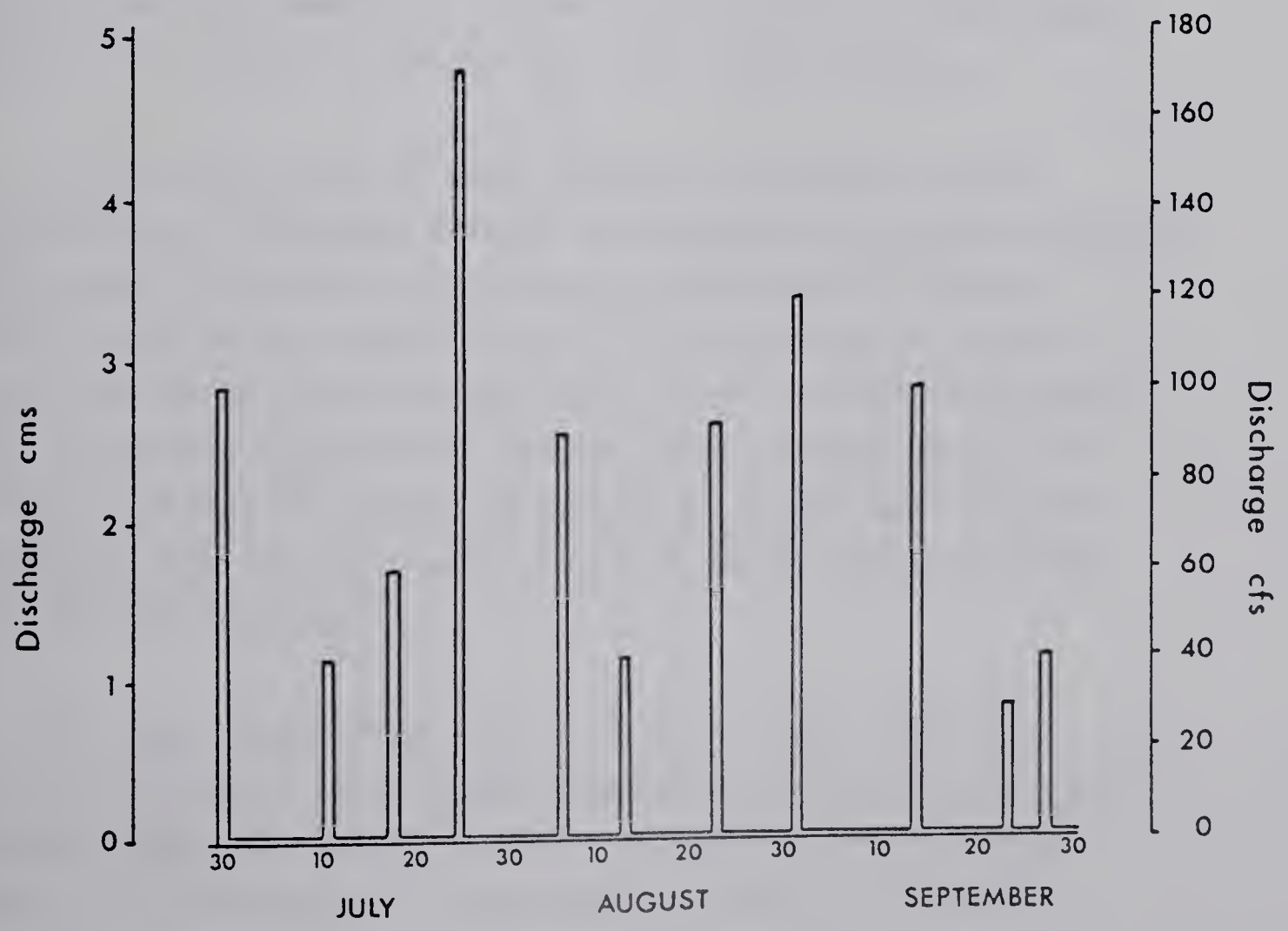


Figure 2.2.e Contemporary Daily Streamflow Patterns of the Kananaskis River Above Pocaterra Creek 1977



The lakes and reservoirs used by TransAlta Utilities follow a storage pattern determined, in part, by operational demands, and also by natural variations in runoff. Chapter 4.4 is a discussion of the fill and drawdown sequences for each major reservoir. Analysis of the data reveals that the reservoirs are drawn down to their lowest storage usually by March so that filling can begin by May or June (Environment Canada, 1980, 1981). Generally the reservoirs are from 80 to 90 percent full by the end of July, although in real values, these differences in water levels can be significant. For example, Barrier Reservoir is often within 1 metre (3.28 feet) of its optimum level, while Lower Kananaskis Lake water levels vary from over 8 metres (26.25 feet) in June to less than 1 metre (3.28 feet) in August, below optimum level. Upper Kananaskis Lake water levels in June average 10.5 metres (34.4 feet) below optimum, while August levels are commonly 2.5 metres (8.2 feet) below optimum.

A combination then of power demands and natural runoff characteristics influence storage requirements and supply scenarios. Since runoff conditions vary markedly from region to region within the District, natural rates of fill also vary. Consequently withdrawal from storage begins first at Upper Kananaskis Lake, continuing from October through March, during which time storage is reduced by almost 80 percent to 25,000 dam^3 (20,000 acre-feet) from its full supply level of approximately 123,350 dam^3 (100,000 acre-feet).

When Upper Kananaskis Lake is at a low level usually in January, withdrawal from storage commences on the Lower Lake and continues until mid-April by which time storage is reduced to almost nil, representing a demand-use of almost 61,675 dam^3 (50,000 acre-feet). Storage is withdrawn in Barrier Reservoir in Mid-April and continues until the end of May, during which

time storage is reduced by almost 90 percent to 2775 dam^3 (2250 acre-feet) from its full supply level of 24,670 dam^3 (20,000 acre-feet).

The contribution which the Kananaskis hydro plants make to the energy grid of TransAlta Utilities may well affect their future operations. At the present (1981) time, the Kananaskis plants, Barrier, Interlakes and Pocaterra comprise 32,800 KW of power generation which represents 10 percent of the generating capacity of the Bow River hydro plants (TransAlta Utilities, 1981). In terms of total TransAlta Utilities generating capacity, Table 2.2a, the Kananaskis plants make up 1 percent of the capacity, and when two additional units at the Keephills thermal generating station come on stream in 1983/84 this contribution will have dropped to 0.8 percent (TransAlta Utilities, 1981). In 1981, gross revenue from sales of energy by TransAlta Utilities amounted to 400.5 million dollars, and hydro generated capacity accounted for 12 percent of this 48.1 million dollars (TransAlta Utilities, 1982). Since the Kananaskis plants comprise 4.1 percent of the hydro generation, this suggests that operations by the three Kananaskis plants could contribute just less than 2 million dollars worth of revenue. This calculation is only an approximation since it does not take into account the amounts of energy actually produced by each plant, operating costs, deferred charges, interest costs and other ancillary costs. It does however provide a perception of the relative worth of the Kananaskis District hydro facilities and operations on an annual basis.

The Electric Utility Planning Council (EUPC) has forecast that the peak demand for electrical energy will increase from 3700 MW in 1980 to 6650 MW by 1988, a 7.7 percent increase per year (Electric Utility Planning Council, 1981). TransAlta Utilities has at present 5300 MW of installed capacity, which means a

Table 2.2a

Generating Capacity of Power Plants by Type and Energy Resource, 1980
(MEGAWATTS)

PLANT	NET CAPACITY 1980	HYDRO	STEAM TURBINE COAL	STEAM TURBINE GAS	GAS TURBINE GAS	INTERNAL COMBUSTION GAS	INTERNAL COMBUSTION FUEL OIL
Kananaskis	18.9	18.9					
Horseshoe	13.9	13.9					
Ghost	50.9	50.9					
Cascade	35.9	35.9					
Barrier	12.9	12.9					
Spray	102.8	102.8					
Three Sisters	3.0	3.0					
Rundle	49.9	49.9					
Bearspaw	16.9	16.9					
Interlakes	5.0	5.0					
Pocaterra	14.9	14.9					
Big Bend	355.0	355.0					
Big Horn	120.0	120.0					
Wabamun	569.0		500.0	69.0			
Sundance	1976.0		1976.0				
Lethbridge	30.7			12.7	18.0		
	3375.7	800.0	2476.0	81.7	18.0		
Edmonton Power							
Rossdale	375.5			317.5	58.0		
Cloverbar	660.0			660.0			
	1035.5			977.5	58.0		
Alberta Power Ltd.							
Battle River	362.0		362.0				
H.R. Milner	140.0		140.0				
Drumheller	-		-				
Ft. McMurray	22.4				3.3	10.6	8.5
Simonette	20.0				20.0		
Sturgeon	18.5				18.5		
Rainbow	58.0				58.0		
Isolated Plants	21.2	1.4			3.3	8.4	8.1
	642.1	1.4	502.0		103.1	19.0	16.6
City of Medicine Hat	136.5			55.5	81.0		
City of Calgary	3.6						3.6
Provincial Total	5193.4	801.4	2978.0	1114.7	260.1	19.0	20.2

reserve of 1600 MW, or 30 percent of the total installed capacity. By 1988 the total installed capacity will have increased to approximately 8000 MW, although reserve capacity will have dropped to 17 percent of capacity. Since the hydro operations are more flexible they are called on to help handle the daily and seasonal peaks, and provide a necessary proportion of potential energy reserve. This suggests that hydro operations will continue to offer a similar regime to that depicted in figures 2.2d and 2.2e for seasonal and daily conditions.

Alberta Environment has used a recently developed water balance model of the South Saskatchewan River Basin to simulate the hydro operations of TransAlta Utilities (Alberta Environment, pers. comm. 1982). The objective was to determine the effects of modifying the operations of the storage reservoirs on system performance. The fill and drawdown sequences for the reservoirs were changed to allow for greater releases in the July-August period, thus having less storage in place for peaking operations during the high energy demand winter months. The results of the analysis and its effects on TransAlta Utilities' available generating capacity (and ultimately financial situation) have not been released, although it has been suggested that the results were less than favourable to TransAlta Utilities (Alberta Environment, pers. comm. 1982).

TransAlta Utilities then, essentially places two types of demands on resource use in the Kananaskis District, ie. demands for land and water. The demands for land are generally static, as no new structural or developmental modifications are envisioned in the near future (Calgary Power Ltd., pers. comm., 1978). The demands for water are volumetrically static; however, the temporal and spatial variations of use of the water resource are subject to changing demand orientations for power and for downstream flow regulations. Thus the extreme temporal variations in streamflow

and storage may pose significant limitations on potential users of the water resources in the Kananaskis.

Demands for recreational use of the resources of the Kananaskis District have increased over the last two decades (Olmstead, 1974). The establishment of Kananaskis Country and Kananaskis Provincial Park helps focus on present and potential recreational uses and their relationship with the water resources of the District. According to the 'Policy for Resource Management of the Eastern Slopes' (Alberta Energy and Natural Resources, 1977) and the policy for Recreation Development of Kananaskis Country (Alberta, Recreation and Parks, 1977) it is government policy to ensure the retention of a variety of natural and developed environments for outdoor recreation purposes. In the Kananaskis District, this concern is best exemplified by the creation of Kananaskis Provincial Park, and a closer scrutiny of Alberta Recreation and Parks' plans for the park will help clarify potential demands on the water resources.

It is no mystery why the park planners chose the extreme southern part of the District as the site for the park. The steep rugged slopes contrasted with the broad rolling valley, and the proximity of glacier icefields and several glacial-fed lakes provided innumerable opportunities for wildland recreational pursuits (Alberta, Recreation and Parks, 1978). It is, in fact, the lakes, streams and Kananaskis River which are cited as major attractions for recreationists who enjoy fishing and boating. The actual use of the water resources for recreation may well be limited due to low water levels during peak user periods, low flow in the major river, late ice cover on the lakes, large expanses of exposed beach, numerous stumps, generally gusty winds and cold water temperatures. It is expected that peak user demand for

recreational use of the lakes and streams would be the July-August period since many of the above factors would come into play up to and including June.

Coinciding with the establishment of the Park will be the increase in withdrawals of water through the drilling of wells (Alberta, Recreation and Parks, 1977). (Osborn and Jackson,(1974) speculate that supplies of groundwater are plentiful in the District, particularly in the tills near the park, and that water shortages should not occur. Concern however is expressed about potential lowering of the water table, and pollution of groundwater from septic tank leachate (Osborn and Jackson, 1974). These concerns may not be justified since return flows from most uses will very nearly equal withdrawals, and as the Park infrastructure expands to include more impervious surfaces including paved roads and rooftops, regional water yield may actually experience a small net increase. The provision of services such as hot and cold running water, showers, etc., may combine to produce a small reduction in local water quality but this need not be significant if properly maintained.

Generally, recreation demands will have two immediate effects on the water resources of the District, non-consumptive uses such as participatory recreation pursuits, and consumptive uses and withdrawals. It has been suggested above that participatory recreational pursuits may be hampered by non-ideal hydrologic conditions early in the summer recreational period. This situation is already coming under close scrutiny due to internal governmental (Fish and Wildlife Division) pressure to improve for recreational use the regime conditions of the major lakes and rivers (Alberta, Energy and Natural Resources, 1980). The existing water management strategy is outlined in detail in Chapter 4, and a discussion of

alternative management strategies which may ameliorate the potential conflicts between recreational demands and current operational plans is the focus of Chapter 5.

The discussion of demands for water in the Kananaskis District would not be complete without a look at some of the downstream influences. The Kananaskis District contributes approximately 16 percent or 447,760 dam^3 (363,000 acre-feet) on an average annual basis to the Bow River, based on the gauge readings upstream from the City of Calgary. Demands on the water system downstream from the Kananaskis District comprise both consumptive and non-consumptive uses, and flow constraints. Irrigation, industrial and municipal water uses, and apportionment and instream quality criteria are discussed below.

Three irrigation districts draw their water supplies from the Bow River below Calgary; the Western (WID), Eastern (EID) and Bow River Irrigation Districts (BRID). Diversions to the Western District generally start in April while the Bow River and Eastern Districts usually draw on internal storage until May, after which diversions by all three districts continue until late September. Irrigation diversions vary on an annual and monthly basis from year to year as a function of the climatic conditions. In 1977, one of the driest years on record, the total diversion for all irrigation districts was 2,140,100 dam^3 (1,735,000 acre-feet), while in 1978 after an unusually wet spring, the total annual diversion was 1,270,000 dam^3 (1,029,650 acre-feet), a decrease of 40 percent from 1977 (Dybvig, 1979). The growth of irrigated hectares in the EID, WID and BRID is illustrated in Figure 2.2f.

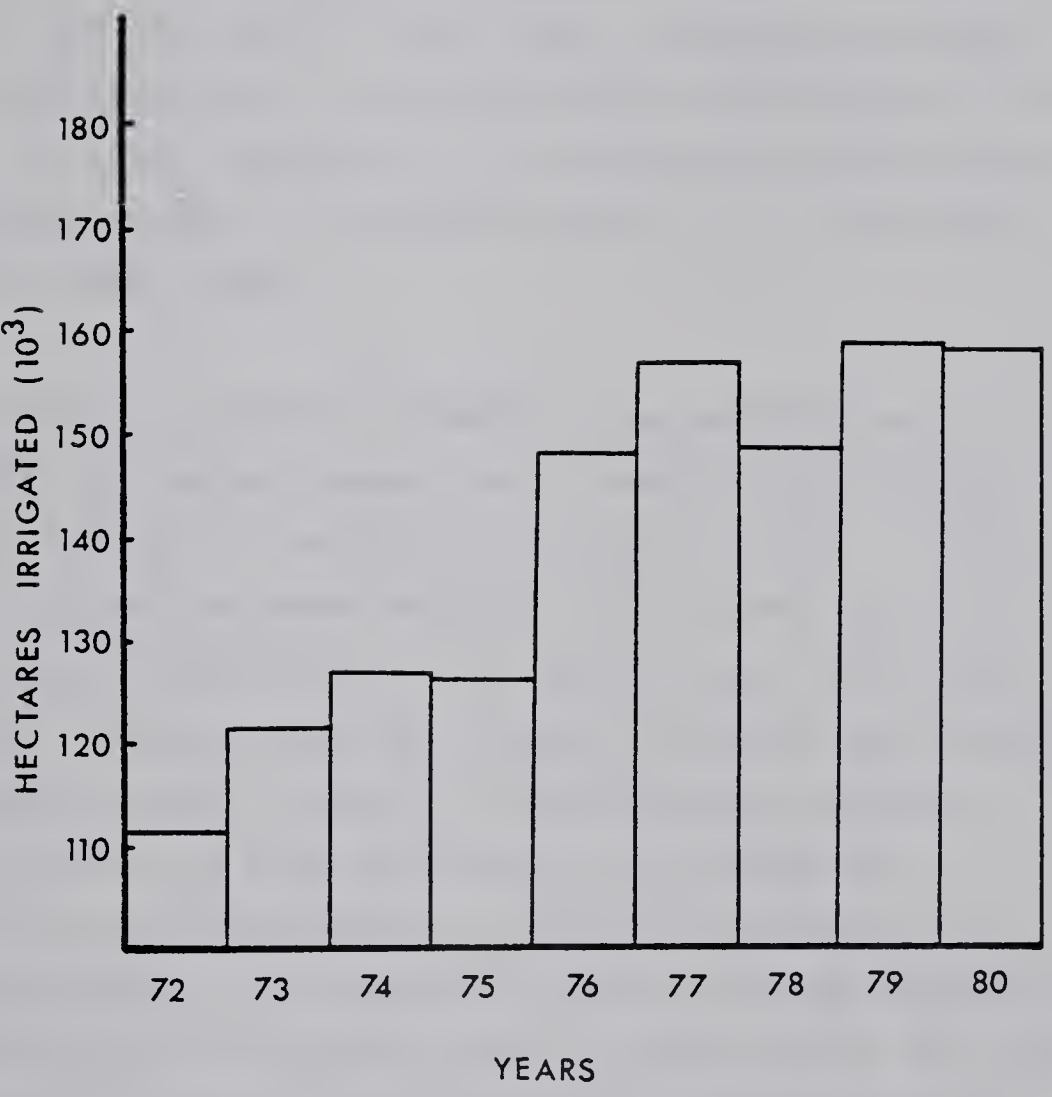


Figure 2.2f Growth of Irrigated Hectares in the Eastern, Bow River and Western Irrigation Districts, 1972 - 1980.

Source: Barnetson, 1981.

The combined total water diversion of the Eastern, Western and Bow River Irrigation Districts in 1979 and 1980 was 1,160,100 dam^3 (940,500 acre-feet) and 1,208,200 dam^3 (979,490 acre-feet) repectively, which accounted for 60 percent of all irrigation diversions in Southern Alberta in these years (Barnetson, 1980, 1981). The seasonal hydrograph of diversions for each of the above three districts in 1979 is depicted in Figure 2.2g. The actual unit consumptive use for the EID, WID, BRID, averaged 5.43 dam^3/hectare (1.78 acre-feet/acre) in 1979 and 5.09 dam^3/hectare (1.67 acre-feet/acre) in 1980, compared to the overall Southern Alberta irrigation consumptive use of 4.31 dam^3/hectare (1.41 acre-feet/acre) (Barnetson, 1980, 1981).

In 1979 the total combined irrigation consumptive use by the EID, WID and BRID (including losses due to evaporation, seepage) was 839,480 dam^3 (680,567 acre-feet) (see Figure 2.2h). In 1980 the amount of irrigated hectares declined 1.25 percent from 1979 levels and consumtive use declined 2.75 percent from 1979 levels (Barnetson, 1981). The declines in irrigated hectares and consumptive use in 1980 are due, in part, to improved soil moisture storage and the removal of some sections to lie fallow and has nothing to do with improvements in irrigation delivery or application efficiencies. In terms of the total average annual water supply of the Bow River as measured near the river mouth, the total combined diversion of the EID, WID and BRID in 1980 amounts to just under 40 percent of Bow River flows. In a dry year, such as 1977, when the discharge in the Bow River measured only 1,390,000 dam^3 (1,126.875 acre-feet), it is apparent that the irrigation districts would have had to rely on internal storage in order to meet the downstream Apportionment Agreement or cut back on the number of hectares irrigated, if local soil moisture conditions and precipitation proved inadequate. Actual consumptive use by the three irrigation districts in 1980 represented 33 percent of the total flow in the Bow River in 1980 and 26 percent of the long term

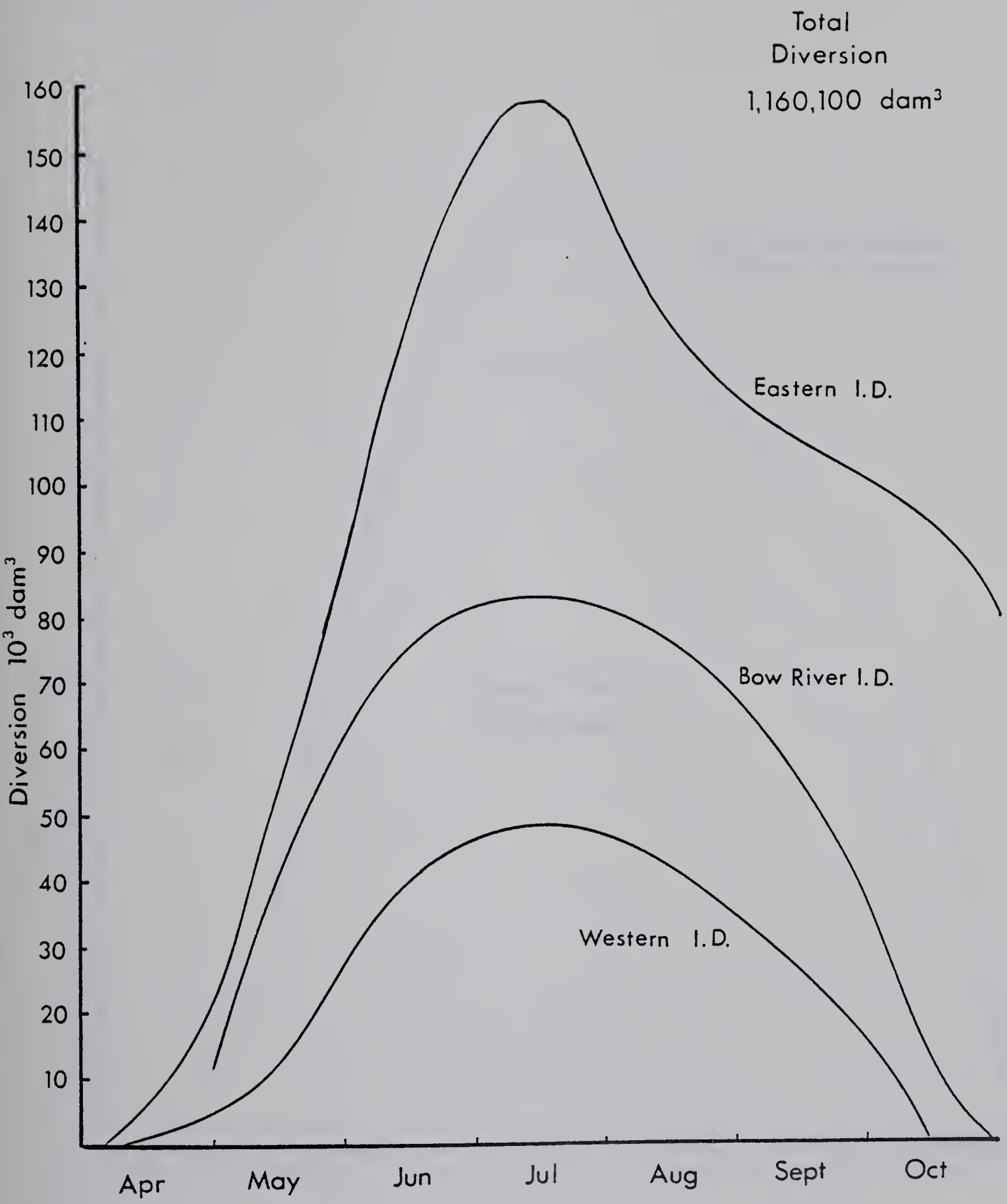


Figure 2.2g Hydrograph of Monthly Diversions for Eastern, Bow River and Western Irrigation Districts, 1979.

Source: Barnetson, 1980.

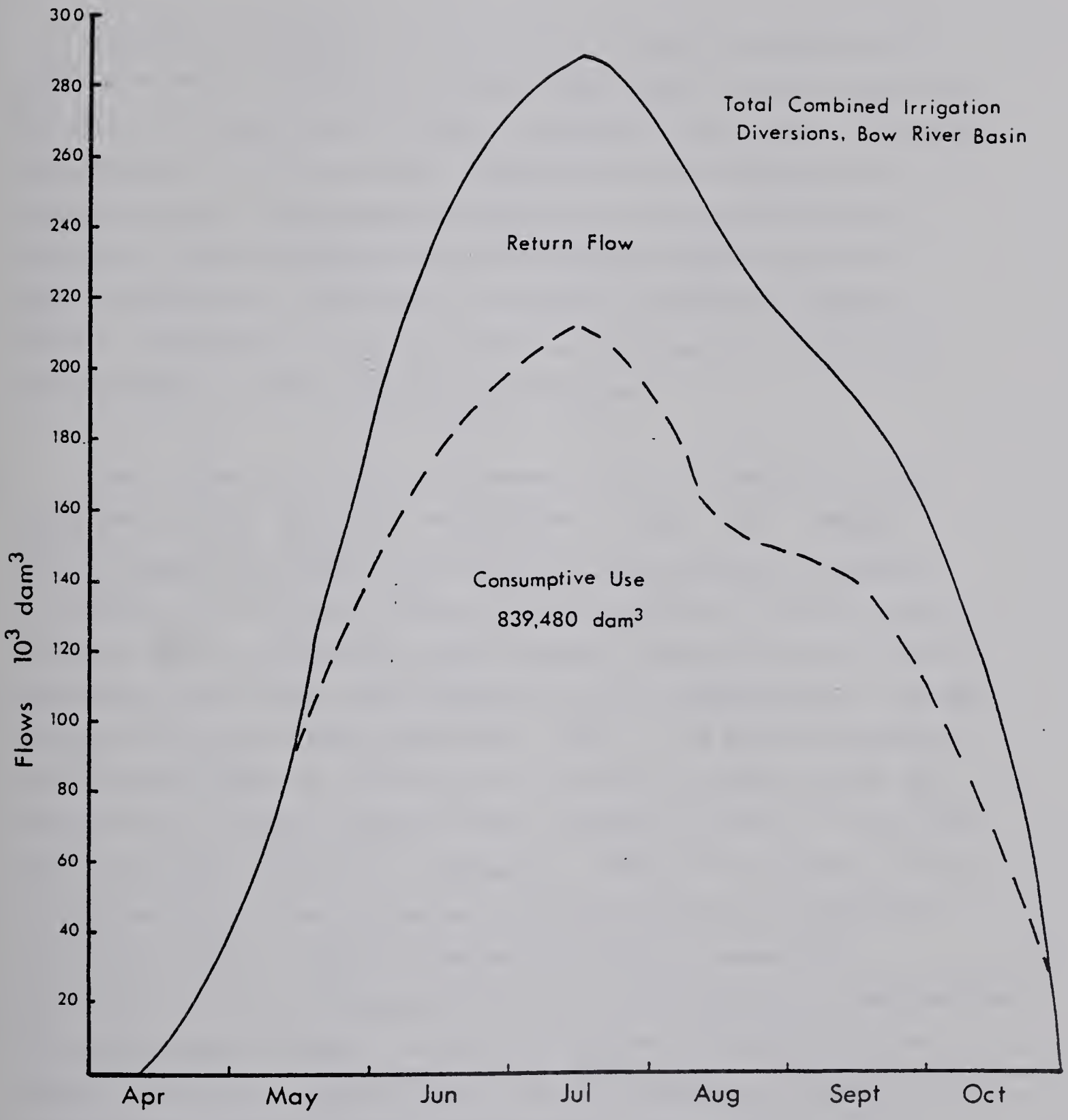


Figure 2.2h Total Diversion and Consumptive Water Use By Eastern, Bow River and Western Irrigation Districts in 1979

Source: Barnetson, 1980.

average Bow River flow.

Studies to determine the potential irrigable hectares and associated water demands in the Bow River Basin have not been conducted to the same extent as for the Oldman River Basin. Internal departmental studies have been conducted by the Planning Division of Alberta Environment in association with the Hydrology Division of PFRA (Prairie Farm Rehabilitation Administration) and the Irrigation Secretariat of Alberta Agriculture (Dybvig, 1976). The results of these studies are presented in Table 2.2b and a comment on their significance follows.

There appear to have been several errors committed in the study and some of these are reproduced in Table 2.2b. Dybvig (1976) suggest that the 1975 levels of total hectares irrigated in the EID, WID and BRID reached 157,928 hectares (390,240 acres). In fact, this is really the total assessed hectares for the three districts, and actual land irrigated in 1975 comprised only 126,000 hectares (311,346 acres) (Barnetson, 1980). The gross diversions for 1975 presented in the table are incorrect as they exceed the actual total Southern Alberta water diversion in 1975 of 1,239,170 dam^3 (1,004,600 acre-feet), (Barnetson, 1980) by 22 percent. The gross diversion values presented by Dybvig (1976) were developed using the value for assessed hectares (which is incorrect) multiplied by the average gross diversion for 1970-74 in dam^3/hectare. Since the gross diversion values and hectares irrigated are incorrect, so are the return flows, and net depletion statistics for the Bow River and the South Saskatchewan River. Taken at face value, with no in-depth analysis, Table 2.2b presents a valid arguement for the need for rather large increases (up to 45 percent) in consumptive use of Bow River waters by 1985. In fact, the

TABLE 2.2b
Assumed Hectares Irrigated, Gross Diversions and Return Flows
Western, Bow River and Eastern Irrigation Districts
Present - 1985 - Ultimate

YEAR	IRRIGATION DISTRICT	HECTARES IRRIGATED	GROSS DIVERSION FROM BOW RIVER (DAM^3)	RETURN FLOWS ($IN DAM^3$ AND AS % OF) GROSS DIVERSION TO BOW	TO RED DEER	TO OLDMAN	NET DEPLETION BOW RIVER (DAM^3)	NET DEPLETION S. SASKATCHEWAN RIVER (DAM^3)
	W I D	18,337	335,340	100,600 (30%)	67,070 (20%)	-		
Present	B R I D	53,325	471,340	150,820 (32%)	-	37,706 (8%)	1,201,600	867,500
	E I D	86,266	710,300	63,927 (9%)	149,160 (21%)	- -		
	W I D	32,255	462,600	92,520 (20%)	92,520 (20%)	- -		
1985	B R I D	76,084	679,430	190,240 (28%)	- -	47,560 (7%)	1,743,800	1,399,600
	E I D	114,935	972,080	87,490	204,130	-		
	W I D	80,940	907,770	108,930 (12%)	163,390 (18%)	- -		
Ultimate	B R I D	121,410	1,093,800	262,530 (24%)	- -	65,622 (6%)	3,410,000	2,770,200
	E I D	222,585	1,955,800	176,020 (9%)	410,730 (21%)	- -		

1 HECTARE = 2.471 Acres
1 DAM^3 = 1233.5 Acre-Feet

Source: Dybvig, 1976

actual water demands are less and are growing at a less rapid rate due in part, to fewer hectares being brought into the irrigation scheme. The statistics presented by Dybvig (1976) for 1975 for hectares irrigated are more in line with those of 1980, although the calculated 1975 gross diversion values of 1,516,980 dam^3 (1,229,829 acre-feet) still exceed the actual 1980 gross diversion by 25 percent.

Whatever the reason for the slower growth in hectares irrigated, whether it is due to weather, soil moisture, economics of crops or costs of irrigating, or due to political interference in the form of a moratorium on irrigation expansion, the rate of expansion in hectares has been far lower (approximately 4 percent between 1975 and 1980) than the 41 percent forecast between 1975 and 1985 by Dybvig (1976). The future expansion of irrigable hectares is difficult to forecast based on past performance, since economics and politics may change in the future. Ultimately the maximum expansion of irrigable hectares will depend on the water supply and how it can be "stretched". Given the present level of irrigation efficiency of 35 percent (Calculated from 1980 return flow versus gross diversion) and the right to consume one half of the mean annual flow in the Bow River as measured at the Bassano Dam, which is 1,255,000 dam^3 (1,017,430 acre-feet), the ultimate level of land irrigated in the Bow River Basin would be approximately 251,000 hectares (620,200 acres). As Laycock (1979) has suggested, several major changes in future water demands may occur largely due to measures that promote more efficient uses of existing supplies and hence, stretch the amount available for use. Some of these measures might include: improvements in irrigation efficiency, particularly at the delivery and application end of things; priorize present uses of water according to more economically important crops;

improve and expand on internal storage from wet to dry years; examine the feasibility of utilizing local groundwater supplies in dry years to supplement available streamflow; or examine methods of costing water supplies such that waste is discouraged. Other alternatives, including water yield management in headwaters areas by deforestation or interbasin transfer, have less to do with improving efficiencies in use, but do exist as possible alternatives until feasibility studies prove otherwise to irrigation expansion.

In essence, the ultimate level of irrigable hectares is constrained, not by available land, but by available water supplies (given that no changes in water supply or use efficiencies occur). If no improvements in use efficiencies are made and the 50 percent downstream Apportionment demand is satisfied, then in a year of average flows, the ultimate level of irrigated land would approximate 251,000 hectares (620,200 acres). At a growth rate similar to the previous 5-year period, this ultimate level of irrigable hectares would be reached sometime before 1985. Of course, any introduction of the efficiency measures described above would change the demand scenario. The role which some of these alternatives might play in overall Bow River Basin water management will be discussed more fully in conjunction with other demands in Chapter 5.

Domestic and industrial water uses place a small but steadily growing demand on the water supplies of the Bow River Basin. The City of Calgary is licensed to withdraw water from both the Elbow River at Glenmore Reservoir and the Bow River at Bearspaw Reservoir. The current (1979) license allows for a withdrawal of 140,620 dam^3 (114,000 acre-feet) from the Bow River; however, only 30.7 percent of this amount was taken in 1978 (Acres, 1980), increasing to 36.5

percent in 1979 and 1980, and increasing further to 39.5 percent in 1981 (City of Calgary, pers. comm., 1982a). Counterbalancing these urban withdrawals is the effect which surface changes, due to increases in impervious area, have had on runoff patterns. The City of Calgary Waterworks Division uses storm water management models (SWMM) to predict storm sewer capacities and the size of storm water retention ponds (City of Calgary, pers. comm. 1982b). The model incorporates the rational formula as a means to develop precipitation-runoff relationships, and employs a runoff coefficient of 30 percent based on impervious surface area (City of Calgary, pers. comm. 1982b). Assuming an average annual precipitation of 457 mm (18.0 inches) and an impervious area of 150 km^2 (58.0 mi^2) out of a total area of 488 km^2 (190 mi^2), direct runoff from the City of Calgary approximates 37,000 dam^3 (30,000 acre-feet) to 49,340 dam^3 (40,000 acre-feet).

An analysis of the City's return flows by Alberta Environment and the City of Calgary (Johnston, 1980) shows that, on average, just less than 80 percent of the water withdrawn for use is returned with a slight quality impairment to the Bow River downstream exclusive of storm water contributions. From 1979 to 1981 inclusive, the City of Calgary withdrew respectively 159,435 dam^3 (129,255 acre-feet), 159,850 dam^3 (129,600 acre-feet), and 164,000 dam^3 (132,990 acre-feet). Based on the 80 percent return flow value mentioned above, in all three years runoff from impervious areas exceeded the amount of water actually consumed. As the amount of impervious area in the City of Calgary continues to grow keeping pace with the population growth, the net water balance will probably show a positive return flow which exceeds water consumption, although the runoff water will be lower in quality due to the addition of salts, oils, grease and sediment from city streets.

While this fact may not have much of an impact on water management by the City of Calgary, it does add an important perspective on overall Bow River Basin water management. This is because in a basin water balance the City of Calgary should be represented by a net gain in water supply, not a net loss as the statistics on demand and consumption would imply. The impression made in Tabele 2.2c on forecasted annual water demand for the City of Calgary, is that increased demands for water (from 3.0 percent to 7.5 percent annually) will ultimately lead to further depletion of the net flow in the Bow River. In fact, actual withdrawals in 1980 and 1981 were 4.3 percent and 8.7 percent less than forecast. Therefore, the assertion that increased urban withdrawals will strain existing water supplies in the near future, requiring further withdrawals or augmentation from other sources and a coincident increase in expenditures, may not be valid.

Gysi (1981) has examined the characteristics of urban water use in Calgary and concluded that the demands for water are artificially high due to waste and inefficiency. An earlier study (Gysi and Lamb, 1977) had shown that the City of Calgary consistently consumed between 30 and 40 percent more water than Edmonton per annum. Most of this difference was attributed to residential consumption (approximately 80 percent of residential customers are unmetered) in unmetered residences where 'flat rate' charges predominate regardless of volume of use. With the existing flat rate charge for water, Calgary residents are not encouraged to conserve or manage their water use wisely. Gysi (1981) attributes this to the large increases in total peak daily consumption, which had averaged between 636 and 727 million litres (140 to 160 million Imperial gallons) until 1979, when the total peak day consumption reached 927 million litres (204 million Imperial

TABLE 2.2c

Forecast Annual Demand - City of Calgary

Annual Demand in Dam^3

YEAR	TOTAL	GLENMORE	BEARSPAW
1980	167,080	108,540	58,540
1981	178,430	108,540	69,890
1982	191,660	108,540	83,120
1983	206,040	108,540	97,500
1984	217,660	108,540	109,120
1985	227,430	108,540	118,890
1986	235,340	108,540	126,800
1987	243,580	108,540	135,040
1988	251,730	108,540	143,190
1989	259,880	108,540	151,340
1990	267,950	108,540	159,410
1991	276,090	108,540	167,550
1992	284,310	108,540	175,770
1993	292,440	108,540	183,900
1994	300,570	108,540	192,030
1995	308,840	108,540	200,300
1996	317,040	108,540	208,500
1997	325,160	108,540	216,620
1998	333,350	108,540	224,810
1999	341,630	108,540	233,090
2000	349,890	108,540	241,350
2001	358,410	108,540	249,870

1 DAM^3 = 1233.5 ACRE - FEET Source: Johnston, 1980

gallons).

Unfortunately Gysi's (1981) analysis contains several significant errors which, if not corrected, give the reader the impression that the City of Calgary is a major consumer of Bow River water. Gysi (1981) has claimed a total annual consumption in 1978 for the City of Calgary of 141,235 dam^3 (114,500 acre-feet), when in fact this was the total withdrawn for use (City of Calgary, 1982a). Total return flow measured 121,548 dam^3 (98,539 acre-feet) (City of Calgary, 1982a), which indicates that actual consumptive use in 1978 measured 14 percent of the figure used by Gysi (1981) (a similar error exists in the other years used in the author's analysis). In addition, Gysi (1981) makes no reference to the volume of runoff in the storm sewer system which the previous discussion has shown could actually exceed the consumptive use in some years. The point is taken, however, that actual withdrawls have increased close to the maximum capacity of the Bearspaw plant due to excessive demands fostered in part by the 'flat rate' pricing of water. In effect, the City of Calgary is responsible for temporary withdrawls which are largely replaced downstream by water which may suffer from a deterioration in quality.

A better perception of the seasonal variations in consumptive use by the City of Calgary can be gained from Table 2.2d. The actual consumptive use for the 1980 and 1981 period as compared to the forecast consumptive use indicated in Table 2.2d did not differ significantly. These values do not take into account the volume of water which returns to the river via the storm sewer system (City of Calgary, pers. comm. 1982a) and as we have seen, in an average year, the net return probably exceeds the present consumptive use. The seasonal patterns depicted in Table 2.2d show an increase in consumptive use to July. This is the time of

TABLE 2.2d

Forecast Monthly Water Consumptive Use - City of Calgary 1980 - 2001
(Million Litres)

YEAR	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.
1980	1100	1118	1714	2737	3623	5110	7155	3432	2659	2009	1705	1587
1981	1177	1191	1828	2923	3869	5455	7642	3664	2841	2146	1818	1696
1982	1264	1282	1964	3141	4155	5860	8210	3937	3050	2305	1955	1823
1983	1359	1377	2114	3378	4464	6300	8824	4232	3278	2478	2100	1959
1984	1436	1455	2232	3569	4719	6655	9324	4469	3464	2614	2209	2068
1985	1500	1518	2332	3728	4928	6969	9742	4669	3619	2732	2319	2159
1986	1554	1573	2414	3855	5101	7196	10078	4832	3746	2828	2400	2237
1987	1610	1627	2496	3991	5278	7446	10433	5002	3887	2928	2482	2314
1988	1659	1682	2582	4123	5455	7696	10783	5169	4005	3023	2568	2391
1989	1714	1737	2664	4260	5632	7946	11129	5337	4137	2123	2650	2469
1990	1768	1791	2746	4391	5805	8192	11474	5501	4264	3219	2732	2546
1991	1823	1846	2828	4523	5983	8442	11824	5669	4391	3319	2814	2623
1992	1877	1900	2914	4673	6160	8692	12174	5837	4523	3429	2891	2700
1993	1928	1955	2996	4791	6337	8942	12542	6005	4655	3514	2982	2777
1994	1982	2009	3082	4923	6514	9192	12874	6173	4782	3614	3064	2855
1995	2037	2063	3164	5060	6692	9442	13229	6342	4914	3709	3150	2937
1996	2091	2118	3250	5196	6869	9692	13579	6510	5046	3800	3232	3014
1997	2146	2173	3332	5328	7046	9942	13924	6678	5173	3910	3314	3091
1998	2200	2228	3418	5464	7224	10192	14279	6846	5305	4005	3400	3169
1999	2255	2282	3500	5596	7405	10446	14629	7014	5437	4105	3482	3246
2000	2309	2337	3587	5732	7583	10679	14984	7187	5569	4205	3569	3328
2001	2364	2396	3673	5873	7769	10960	15352	7360	5705	4305	3655	3405

1 Litre = 4.546 Imperial Gallons

Source: Johnston, 1980

year when lawn-watering, car washing and other home-related uses are at their peak, creating significant losses due to evaporation and seepage to groundwater. As the demand and consumptive use for water peaks in July, the rate of return flow decreases to 60 percent of the total demand (City of Calgary, pers. comm. 1982a). In contrast the winter period is characterised by lower demands and consumptive use, and higher return flows (ie 90 percent of demand flows).

In essence, the patterns of urban water demand and consumptive use follow a seasonal high summer peak, low winter cycle. On average, approximately 80 percent of the water withdrawn to meet urban demands is returned to the Bow River system. In addition, this return flow is supplemented by storm water runoff which the City of Calgary Waterworks Division calculates is equal to or exceeds consumptive use. This implies that use of Bow River water by the City of Calgary should not seriously affect downstream users, although water quality may be slightly impaired from runoff sources. As treatment facilities improve at the Fish Creek and Bonnybrook plants, to remove more of the inorganic substances, quality concerns should diminish, although increases in the total quantity of effluent treated coincident with the population increases will strain the facilities thus requiring expanded treatment units. The growth in water demand has in recent years reached near capacity of the Bearspaw plant, and current expansion of the plant facilities to 1364 million litres per day (300 million imperial gallons) from 955 million litres per day (210 million imperial gallons) might not have been required right now if metering, cost and conservation policies were adopted by the City of Calgary.

The total industrial water diversion from the Bow River at present amounts to about 0.425 cms (15 cfs), and approximately 60 percent of this is returned (Dybvig, 1979). Although this could increase substantially it is unlikely that the net withdrawal would have any significant effect on Bow River operations by TransAlta Utilities, since flow increases with surface changes probably exceed consumptive use.

Two forms of flow constraints affect Bow River operations on a daily and annual basis, apportionment and instream flow constraints. Based on a 1969 agreement between Alberta, Saskatchewan, Manitoba and Canada, Alberta has the right to consume one-half the natural flow originating in the South Saskatchewan River basin, or a quantity of 2.6 million dam^3 (2.1 million acre-feet) whichever is the largest, on a calendar year basis. In addition, the natural flow of the South Saskatchewan River below the junction with the Red Deer River is to be maintained at a minimum of 42.5 cms (1500 cfs). Normally the major releases by TransAlta Utilities are made during the months of December, January, February, March and April giving rise to flows far in excess of the natural flow. These releases help offset the large compumptive withdrawals during the summer by irrigation districts thereby helping to meet Alberta's calendar year apportionment commitment (Dybvig, 1979).

It is conceivable that as more demand is placed on water in the South Saskatchewan River by Saskatchewan attempts might be made to have the apportionment period renegotiated from a year to something less than a year. If the period was shortened, then

increase demands might be placed on storage in the TransAlta Utilities reservoirs in a dry year like 1977, presuming that irrigation demands are not curtailed. In 1977, the recorded flow in the winter was in the order of 150 percent of natural flow whereas during July it was 40 percent of the natural flow (Dybvig, 1979). Over the calendar year Alberta met the apportionment commitment. However, it goes without saying, that if the apportionment period had been one month, irrigation withdrawals would have had to have been severely cut back, or additional releases would have had to have been made from the upstream reservoirs. Some initial interest had been expressed in the early 1970s by the Province of Saskatchewan to re-examine the time frame under which minimum flow levels would be guaranteed (Alberta Environment pers. comm., 1982). However, the Province of Alberta showed no interest in renegotiating the agreement, and pointed out in its defence that Lake Diefenbaker was more than capable of handling the present and future needs for water demand in Saskatchewan (Alberta Environment, pers. comm., 1982). Apparently, the Province of Alberta was concerned that any change in the apportionment time frame would seriously affect the withdrawals of the irrigation districts and require larger releases from the upstream reservoirs, in turn affecting the hydro operations of TransAlta Utilities. Therefore, if the apportionment period should be re-evaluated, additional demands could be placed on TransAlta Utilities reservoirs unless additonal storage from wet to dry years is constructed, or reduced emphasis is placed on meeting irrigation demands.

According to a verbal agreement between TransAlta Utilities and Alberta Environment, it is desirable to maintain a minimum flow in the Bow River below the Bearspaw Reservoir of 42.5 cms

(1500 cfs) for water quality (Acres, 1980). On the average the natural flow in the Bow River through Calgary is approximately 25.5 cms (900 cfs) during the winter months, although in recent years the flow has generally been augmented by 19.8 cms (700 cfs) to 28.3 cms (1000 cfs) during the October to March period as a result of releases from TransAlta Utilities reservoirs. Currently this augmentation complements the desired hydro-electric generation requirements of TransAlta Utilities.

The South Saskatchewan River (at its junction with the Red Deer River) is, by agreement between the Provinces, to be maintained at a minimum flow of 42.5 cms (1500 cfs) (Dybvig, 1979). However, a review of the historical streamflow record, reveals that since 1966, this flow constraint has been violated in every year but two. If the Saskatchewan government were to complain and demand its agreed upon minimum flow, the Minister of Alberta Environment could direct TransAlta Utilities to increase releases from the upstream reservoirs as one recourse.

To adequately maintain water quality in the Bow River through Calgary, Acres (1980) has estimated that in the future (approx. 2001) the instream requirement at Calgary would grow to approximately 1,339,500 dam^3 (1,086,000 acre-feet) per year. This would be the minimum yield required, yet the reliable annual yield from the Bearspaw Reservoir is inadequate to meet this minimum flow requirment during critical times. Since the Elbow River is tapped almost to its licence limit, one alternative to constraining downstream demands is to regulate the upstream reservoirs of TransAlta Utilities to meet the instream requirements at Calgary during low flow periods. The implications of this management strategy on TransAlta Utilities operations and on other potential users will be examined in detail in Chapter 5.

2.2.3 Summary of Demand Assessment

Demands on water originating in the Kananskis District are derived from both internal and external sources. Water is used internally to provide storage for later use in hydro power production and for recreational pursuits. Externally, Kananaskis water is used to help with Bow River flow regulation, municipal and industrial uses, irrigation withdrawals, and to help Alberta meet its downstream Apportionment agreement with Saskatchewan.

TransAlta Utilities, a private utility company, has developed 209,700 dam^3 (170,000 acre-feet) of storage in the Kananaskis District which is used to store spring snowmelt runoff for later use in peaking power production. The actual operation of the Kananaskis power plants is determined by a combination of external demands for peak power and internal runoff conditions, as there are no constraints in the water development licenses which govern daily, monthly or seasonal flows for the Kananaskis River. As a result streamflow can vary from a low of 0 cms to over 28.3 cms (1000 cfs) in a 24 hour period. In general, water levels in the reservoirs are drawn down throughout the winter and are at their lowest level in early spring in time for the spring runoff event. The reservoirs are filled over the summer period and are usually several metres below full supply level throughout the summer, reaching full supply level in September or October. The generating capacity of the three Kananaskis plants comprises 10 percent of Bow River hydro capacity and 1 percent of the present TransAlta Utilities generating capacity. Forecast energy demands for the 1980s show a 7.7 percent increase per year, and although total installed generating capacity will increase to 800 MW by 1988, reserve capacity will actually decrease. Since hydro operations are more flexible, the reservoirs are used

to handle the daily and seasonal peaks and provide a necessary proportion of energy reserve. Therefore, system management in the future is not expected to differ significantly from the existing mode of operations.

Demands for recreational use of the land and water resources of the Kananaskis District are best exemplified by the creation of Kananaskis Country and Kananskis Provincial Park. Generally recreation demands will have two immediate effects on the water resources of the District, non-consumptive uses such as participatory recreation pursuits, and consumptive uses and withdrawals. Popular non-consumptive uses would include fishing, boating and aesthetic viewing. The Policy for Recreation Development in Kananaskis Country identifies fishing as the only important waterbased recreation activity, although government literature on Kananaskis Country and Kananaskis Provincial Park identify boating on the lakes as a potential recreational pastime. However, the realization of these uses may be hampered by conflicts with TransAlta Utilities. For example, the 28 cms (1000 cfs) range in flows due to peaking demands has been linked to the scouring of fish spawning beds and the minimal sport fish populations in the Lower Kananaskis River. In addition, lake levels are normally well below optimum level during the summer recreational period which will affect boat launching, and the exposed mud flats dotted with rotting stumps are not aesthetically pleasing. Since several of the recreational facilities to be developed, including the Barrier Lake day use area, Evans-Thomas Alpine Village, and Upper Kananaskis Lake campground, are planned to take advantage of the aesthetics offered by nearby water bodies, it is obvious that water will play a more significant role in recreation than outlined in the Policy. Actual withdrawals and consumptive use of water supplies will be small. In most cases,

water provided for recreational amenities will be derived from groundwater wells and any consumption should be more than balanced by return flows and increases in local yield from impervious surfaces such as rooftops and roads. Although a small reduction in water quality is possible, proper waste-water management can reduce this to minimal levels. It would appear then, that the non-consumptive participatory recreational pursuits may be hampered by non-ideal hydrologic conditions if present use orientations continue.

There are no existing legal flow constraints in effect on the Kananaskis River. There are however, several flow guidelines for the Bow and South Saskatchewan Rivers in which Kananaskis waters play a part. Traditionally, it has been desirable to maintain a minimum flow in the Bow River at Calgary of 39.6 cms (1400 cfs) for water quality concerns. During the winter months, the low natural flow of 25.5 cms (900 cfs) has been augmented by releases from the upstream reservoirs. Since this demand complements TransAlta Utilities present winter operations no major conflicts are forseen.

The South Saskatchewan River, at its junction with the Red Deer River, is supposed to be maintained by a combined Oldman, Bow and Red Deer River contribution at a minimum of 42.5 cms (1500 cfs). A review of the streamflow records reveals that since 1966, this flow constraint has been violated in every year but two. To meet this flow constraint, the Minister of Alberta Environment could direct either TransAlta Utilities to release more water from the upstream reservoirs, or reduce the withdrawals by the irrigation districts. The repercussions of this demand being pressed by the Saskatchewan government in the future could conflict with upstream uses.

Municipal and industrial demands appear significant on the surface but in fact the short-term withdrawals are more than counter-balanced by return flows from all sources. Certainly the urban demand for water increases as the population increases, but this demand is artificially high since the unmetered water use policy by the City of Calgary and the 'flat-rate' charge system encourage over-use. For the past several years approximately 80 percent of the water withdrawn for use is returned to the Bow River after treatment. Seasonally this return flow will vary from a low of 60 percent of the water withdrawn during the summer months, to a high of over 90 percent withdrawn during the winter months. In addition, the return flows are supplemented annually by contributions from storm water runoff and snowmelt, due to changes in the surface characteristics, resulting in a net increase in flow in the Bow River below Calgary.

Irrigation requirements on the Bow River water comprise the largest and most contentious demand. The number of hectares irrigated in the Bow River basin, has increased in recent years, although more slowly than was forecast, at approximately 4 percent per year since 1975. Similarly, withdrawals have increased, less than forecast, at an average annual rate of 4.1 percent to 1,208,200 dam^3 (979,490 acre-feet) in 1980. Actual consumptive use by the Eastern, Western and Bow River Irrigation Districts in 1980 represented 67.5 percent of the water withdrawn for use, but only 33 percent of the total flow in the Bow River in 1980. The present level of irrigation efficiency of 35 percent is responsible for the greater than average duty of water per unit of land at 5.09 dam^3/hectares (1.67 acre-feet/acre).

Attempts to determine the amount of potential irrigable land available in the Bow River Basin, and hence the potential water demands on the Bow River, have not been as rigourously studied as they have in the neighbouring Oldman Basin. An internal government report which attempted such a study, contained significant errors and biases such that the results were reflective of unrestrained irrigation expansion requiring massive amounts of water far beyond the limit to which Alberta is entitled. It is certain that unless efficiencies of water delivery and application are improved, the ultimate limit of irrigable land in the Bow River Basin would reach approximately 251,000 hectares (620,200 acres) in an average flow year and somewhat less in dry years.

This is also dependent on the continuation of the agreement which allows for 50 percent consumptive use of the water in the Bow River Basin. If any of these variables change, then the ultimate level of irrigable land will change also. Other variables, including priorization of water allocation dependent on crop type, increasing the cost of water, using local groundwater supplies in dry years, and providing better internal storage from wet to dry years, can also influence the amount of irrigable land. As the amount of irrigable land increases, so does the water demand and Alberta comes closer to the allowable limit under the Apportionment Agreement.

The Apportionment Agreement signed in 1969 gave Alberta one-half the natural flow of rivers rising within provincial boundaries. For the South Saskatchewan River basin, this means one-half the flow or 2.6 million dam^3 (2.1 million acre-feet) whichever is largest

on a calendar year basis. The Bow River has contributed, on average, 3,210,000 dam^3 (2,602,350 acre-feet) from 1964 to 1979, to the South Saskatchewan River. In 1977, one of the driest years on record, the flow contributed by the Bow River fell dramatically (as it did in the Oldman and Red Deer Rivers) to 1,390,000 dam^3 (1,126,900 acre-feet), and the combined flow of the three rivers satisfied the minimum Apportionment level by only 750,000 dam^3 (608,000 acre-feet). This would suggest that in dry years similar to 1977, some irrigation demands may go unfullfilled if Apportionment is to be satisfied. Any attempt to renegotiate either the amount or the time frame of the Apportionment Agreement by Saskatchewan would be vigorously opposed by Alberta.

The demands on the water supply of the Kananaskis District will come under increasing pressure from internal and external sources. The actual present supply of water, and its potential for management for future use, is largely dependent on the physical and hydrological characteristics of the District. The following is a discussion of the regional analysis methodology which serves as a tool for describing the nature of the physical water supply patterns in the District.

2.3 REGIONAL ANALYSIS METHODOLOGY

2.3.1 Potential Water Management Objectives

The major objectives in watershed management are improvement in water yield, regime and quality, reduction of erosion and flood

damage, and improvement of lake, stream and streamside habitat (Laycock, 1973). Water yield increases have been stressed by several agencies (Eastern Rockies Forest Conservation Board; Canadian Forestry Service) as being the major management objective in water resources for the Eastern Slopes (Swanson, 1977). Laycock (1973) suggests that as much as 10 to 20 percent more water could be obtained from the Eastern Slopes by removing all the vegetative cover, thus effectively reducing large transpiration losses. While complete removal is an extreme measure it is also impractical, since the increase in erosion and flood damage, and impairment of flow regime and water quality would be extremely costly. Other methods of improving yield including changing cover species and composition in favour of shallow rooting plants (Goodell, 1967), or by high elevation snow management (Anderson, 1963; Golding, 1974, 1977; Martinelli, 1975; Packer, 1971) have been advocated with varying degrees of success. Laycock (1961, 1973) commented on the limited potential for further yield increases from forest management due to the extensive fires of the past several decades, which have in practice already increased the total water yield from the Kananaskis District and other areas of the Eastern Slopes. As the existing forests mature, it is to be expected that regional yields will decline. With continued fire protection water yield improvement is inhibited. Since fire protection is a prerogative of the agencies involved in management of the Kananaskis District little change in flow volumes can be expected. However, the various alternative methods on how to achieve yield increases will be examined in conjunction with present and forecast demands for resource use in the Kananaskis District in Chapter 5.

Regime improvement is the ideal water management objective since it implies a more seasonally equitable supply. Natural flow regime patterns will vary from region to region, but generally mountain runoff patterns peak in late spring - early summer and decline to low winter base flow. The objective behind many structural measures is to delay the peak or diminish its volume so as to provide assured supplies in low flow periods. Artificial storage, with release at desired times and rates in know quantities, can be useful in many areas but costs, use conflicts and the relative lack of current demand in the Eastern Slopes are such that only the most favoured sites for development should be considered (Laycock, 1973). In the Kananaskis District this method has been effectively employed for almost 50 years (Calgary Power Ltd., 1973).

Most areas could be improved in flow regime pattern if an emphasis on an abundant and mature vegetation cover is made. This form of vegetation management would result in more extended snow melting, better surface detention of snow and rain, better infiltration of moisture into soils and percolation through them to groundwater detention storage, and far slower release to streams (Laycock, 1973). Consequent with regime improvement is the reduction in potential for flooding and associated problems of erosion, sedimentation, and reduction in water quality.

Erosion and sedimentation problems occur naturally as well as through human efforts, and depending on the user orientation can be reduced using structural and non-structural mitigative measures. Natural erosion and sedimentation of streams occurs through mass-wasting from hillslopes and river processes. Aside from catastrophic land slide events, or sudden changes in river grade or discharge, most natural erosive processes occur slowly,

often with little visible evidence of sedimentation. Man's influence through various land use changes is often more immediately apparent.

Rothwell (1971) has indicated the degree to which certain construction and forest operations influence rates of downslope sediments in streams in Marmot Creek in the Kananaskis District. Generally, forest practices such as cutting or burning initiate accelerated soil erosion due to scarification in the former case, and removal of anchoring vegetation in both cases. Rothwell (1971) has also indicated the use of potential mitigative measures for reducing erosion following forest cutting and road construction practices.

Certain non-structural management measures, such as encouraging forest growth through an active forest fire prevention program, ensures a stable surface mat of vegetation which anchors the soil and reduces erosion due to raindrop splash and snowmelt runoff.

Land use policies and strict management guidelines are useful measures which can be regionally adapted where use conflicts are present in particular site situations. Forestry can be complementary if cutting schedules are related in part to water yield increase needs, and competitive if they are not (Laycock, 1973). Erosion damage from forest cutting operations is rarely significant for more than a few years, while damage to the regime characteristics could last for several decades (Laycock, 1973; Neill, 1977; Swanson and Hillman, 1977). Recreational use can result in erosion acceleration and less favourable regime patterns, but reasonable site selection for potential problem uses and reasonable care in road and trail development can produce minimal negative effects (Laycock, 1973). Even wilderness areas and areas with wildlife

management orientations can have both positive and negative effects on water management. Positive effects can be evident if the wilderness area is protected from fire and the watershed management objective is one of regime improvement through encouraging maximum vegetative growth. If the management objective is one of promoting water yield increases through forest cutting, or if the watershed is in poor shape, and regime improvement and erosion and sedimentation reduction is desired, these measures would be in conflict.

Flood limitation is generally achieved through structural measures, although encouraging a dense forest cover through proper cutting and fire prevention measures can also help limit flood damage. Also, reduced flood flows mean less erosion and sedimentation of streams and reduced potential of water quality deterioration.

Environmental enhancement of lake and streamside areas can be achieved using several alternative measures. Management of strip vegetation including species replacement, better flow control to reduce stream bed scour, controlled access for recreational users to minimize bank erosion and slumping, better control of snowmelt events and deposition of debris and sediment into reservoirs and streams, are all useful measures. Some measures are compatible with other use objectives; however the techniques employed will depend on particular site conditions and overall management objectives.

It is clear then that the objectives and measures employed for watershed management should be well adapted to regional needs and possibilities for regional development. The problem analysis approach advocated by Wilm and Dunford (1941) suggests that the unique

water demand/supply relationships be assessed so that regional objectives can be properly defined. The potential conflicts that can arise when management objectives are poorly suited to regional needs is apparent from the above discussion. The choice of watershed objectives will depend to a considerable degree on the physical compatability of the region to provide the resource and support the management techniques. Therefore an analysis of the region's physical hydrologic base, preceded by a discussion of the assessment criteria and classification employed is necessary.

2.3.2 Watershed Soils Classification

The classification used in surveying the soils of mountain watersheds will depend largely on the potential use of the information acquired. Most watershed soil surveys are conducted to provide information for management planning in the watershed region (Laycock, 1958). The information required will depend on user orientations and management objectives. Soil characteristics such as infiltration and percolation capacities, retention and detention storage capabilities, erodability of soil and natural influence of underlying bedrock must be understood before the effects of different kinds and intensities of use upon the soils can be predicted (Laycock, 1958).

The conventional pedologic classifications used for agriculture surveys are not well suited to mountain watershed surveys since the objectives are not the same and much of the information gathered is of little use in hydrologic studies. Since most mountain soils are intrazonal or azonal, due in part to the climate, vegetation and time since last glaciation, the full depth of loose surface materials over the bedrock may be included in the term soil (Laycock, 1958). Thus the term soil is interchangeable here with surficial materials where watershed characteristics are discussed.

Several surveys have been made of the surficial materials and soils separately in the Kananaskis District, with little or no regard to watershed characteristics. Karkanis (1972) mapped the soils of the Kananaskis valley and demonstrated that regosols (properly identified as soils without genetic horizons) dominated, while other soil groups are generally dispersed, valley oriented and exceedingly thin, in the order of 2 cm. (0.8 in.) to 5 cm (2.0 in). This is understandable given the generally cold climate and short time since the last ice age which contribute to very slow soil development. An attempt to use the Soil Classification of Canada for hydrologic purposes (Beke, 1969) in a mountain environment proved less than useful due to the overwhelming influence of the underlying parent material on water infiltration, retention and runoff characteristics.

Several investigations of surficial materials have taken place in the Kananaskis District, with only marginal emphasis placed on the hydrologic characteristics of these materials. Rutter (1965, 1968) and Walker (1971) studied the deposits of the northern entrance to the District according to conventional geomorphic methods. Duffy and England (1967 classified surficial materials on the basis of forest land use within the Kananaskis Forest Experiment Station in the northern section of the District. Stalker (1973) mapped surficial materials in the Marmot Creek Experimental Basin and in the Kananaskis Forest Experimental Station on the basis of genesis. Osborn and Jackson (1974) utilized air photos and field investigations to produce an intensive study of material types, their extent, distribution and properties for the entire Kananaskis District. Jackson (1977) produced a Ph.D. thesis based in part on this work for a much larger area for the purpose of terrain inventory. The most recent study by Bayrock and Reimchen (1977), an interim open file report for the Alberta Research Council, duplicated much of Jackson's (1977) work. There are numerous differences in materials identification and classification, largely due to the definition of terminology used, however the original study (now in the process of being revised) suffered from an overly ambitious degree of generalization due to the large area under investigation.

The studies discussed above are similar in that they did not contain information specifically oriented to watershed concerns, since their objectives were intrinsically geomorphic or academic. In order for the soils information to be of use in watershed planning, the surveys must be conducted for this purpose, emphasizing

the hydrologic characteristics of the individual soil units. In mountain watershed soil surveys, the classification must have relatively few distinct categories so that the mapping units will be large and may, singly or in simple combination, be used as management units (Laycock, 1958).

The classification used in this study is a slightly modified version of the one used by Laycock (1952-1955, 1957a, 1958) in the original watershed soil surveys in the Eastern Slopes for the Eastern Rockies Forest Conservation Board. In these early reports, a separate category termed residual soils (ie. soils with some horizonal development) was included in the classification. This term has been omitted in this study since their recognition required a far more intensive level of investigation than was warranted, particularly in light of Karkanis' (1972) results. A brief description of each unit's watershed characteristics follows, abstracted from Laycock (1958).

Division 1 includes all bare rock, rocky alpine and glacial areas in which profile development is negligible and surface materials are absent, thin, or very coarse textured. These areas have very limited detention or retention storage capacities, and runoff is generally rapid since vegetative cover is absent or sparse. Water yields are high and regimes are extremely variable and seasonally disproportionate.

Division 2 includes all soils formed primarily of gravity fallen materials and termed colluvial soils. Located on or at the base of steep slopes, these soils are coarse in texture and of variable depths, with characteristically high porosity. Thus a large amount of detention storage capacity exists for ice, snow and frost which can be maintained well into the summer months. The porous nature of these deposits ensures that drainage can be rapid

and therefore retention storage is small. Water yields are generally large since use by plants is small although much of the water drains into other deposits down slope.

Division 3 includes all glacial deposits except those of glacial-fluvial origin. These soils (tills) are generally deep and have variable textures, and are located on the lower slopes where they provide detention storage for runoff from higher levels. Retention storage for plant use is usually high while water yields tend to be low for a given precipitation event. Erosion can be a problem on the finer tills.

Division 4 includes alluvial and glacio-fluvial soils which are located in valley bottoms. Thin layers of fine textured alluvium may overlie coarser glacio-fluvial materials, and while detention storage is excellent, retention storage is not adequate in these shallow layers for tree growth. Regimes are generally good and yields are low, thus flooding is limited although erosion from over use can be a problem.

Division 5 includes all poorly drained soils where palustrine soil development and glei horizons are common. These soils allow gradual movement of water to streams, yet their watershed conditions are not ideal for there is generally little unused storage capacity for handling heavy rains. Depending on the precipitation characteristics of a season, runoff, infiltration, evapotranspiration and regime may all be highly variable.

In the summer of 1978 this author undertook, as part of the overall study, an investigation of the broad patterns of watershed soils by utilizing air photos and random field checks. The subsequent patterns developed from the classification discussed above are derived from the combined observations of the previously noted references and personal observations. Figure 2.3a depicts the major watershed units for the Kananaskis District.

Generally, colluvial soils occupy the largest surface area within the district although, in many areas these are thinly spread over till and glacio-fluvial soils. These soils are well located from a watershed point of view as they are in position to receive the runoff from bare rock areas and coarse colluvium lieing upslope. The alluvial and glacio-fluvial soils can be found predominately in and adjacent to streams and are at their greatest extent at the confluence of the Kananaskis River with Evans-Thomas Creek. Bare rock areas are predominantly located along the higher ridges, with only minor exposures occuring in the river valleys, while glacial ice is found only on higher north-facing slopes. Poorly drained soils (marsh deposits) can be found locally near the Kananaskis Lakes and in the Pocaterra Creek - Elbow River watershed divide.

2.3.3 Climate Analysis

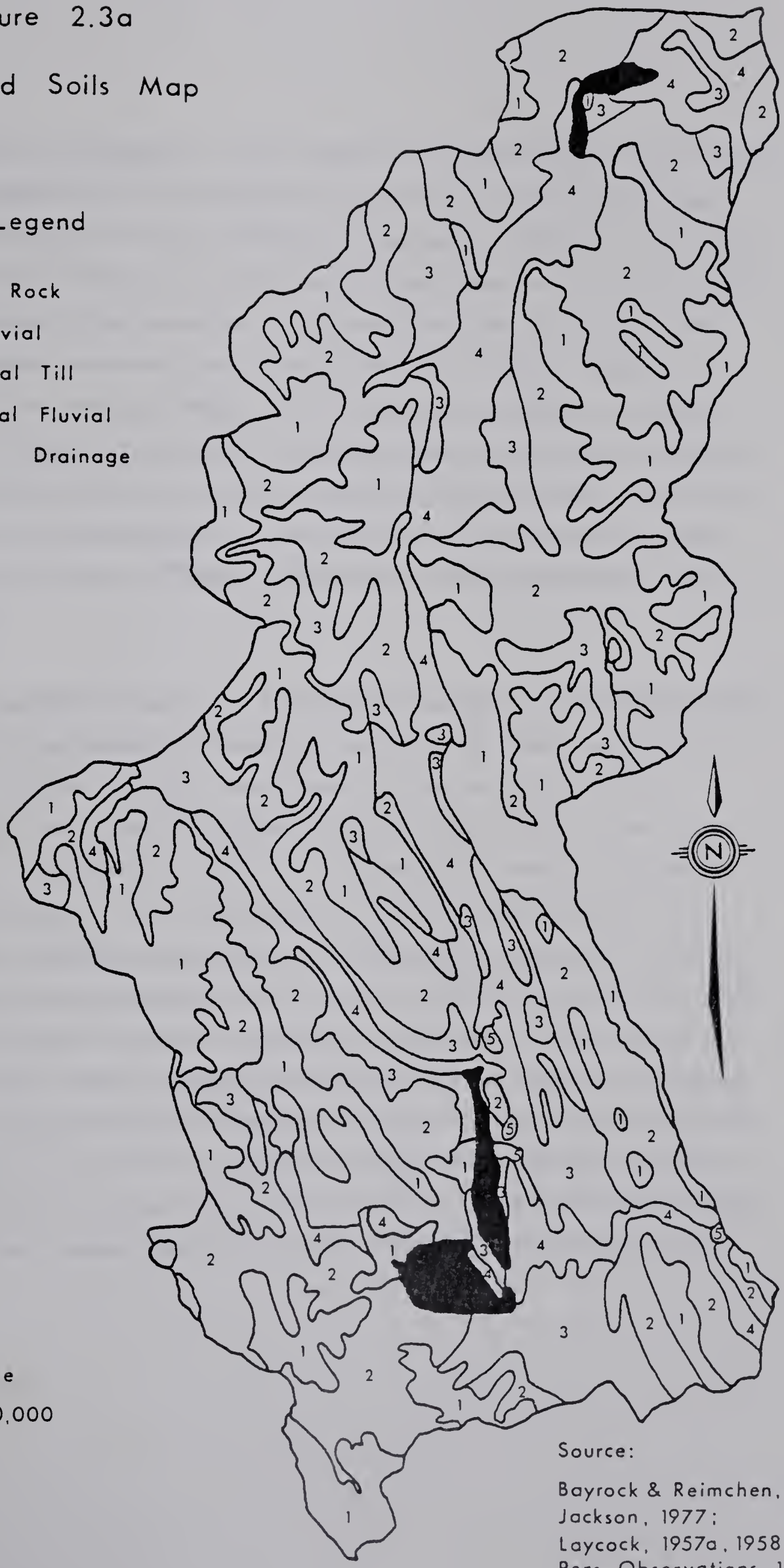
In developing a State Water Plan for the State of Idaho, it was deemed necessary to have a comprehensive analysis of the climatic variables which influence the regional hydrologic patterns (Idaho Water Resource Board, 1968). In several areas of the State, particularly the high mountainous regions, climatic information was

Figure 2.3a

Watershed Soils Map

Legend

1 Bare Rock
2 Colluvial
3 Glacial Till
4 Glacial Fluvial
5 Poor Drainage



Scale

1:250,000

Source:

Bayrock & Reimchen, 1977;
Jackson, 1977;
Laycock, 1957a, 1958;
Pers. Observations, 1978

often absent or incomplete. As a means of establishing the climatic patterns (especially precipitation) and of substantiating data from existing meteorologic networks, innovative hydrometeorologic techniques were employed. The climatic patterns were mapped using iso-elevational relationships developed from the literature and supported where necessary with water balance studies (Idaho Water Resources Board, 1968). This information, when correlated with known climatic patterns in neighbouring states and provinces was used to help define the water resource inventories, and later to support the development of the regional water resource plans adopted by the State of Idaho (Idaho Water Resource Board, 1972, 1974, 1976).

The problems involved in a climatic analysis of the Kananaskis District and the Eastern Slopes are similar to those experienced in Idaho. Several authors have lamented the scarcity of the meteorologic date base including Longley (1967, 1972), Janz and Storr (1977) and Powell (1977), in attempts to develop regional climatic patterns. Few researchers are willing to deviate from conventional analysis techniques for developing specific climatic patterns such as precipitation. Laycock (1957b, 1961, 1967, 1978) has shown how water balance techniques, similar to those used in Idaho and other State framework studies, can be useful in helping to develop regional runoff patterns. Also the use of other forms of information such as soil types, vegetation, snowline and snow drift maintenance variations, can be useful in helping to estimate precipitation, evapotransportation and runoff characterisitics.

While the geographical and physiographic characteristics of the Eastern Slopes are the dominant influence of the macro-climatic patterns, the focus of management concerns is more often on the intra-regional climatic variations. The Kananaskis district, with its unique blendof mountains, valleys and slopes will undoubtedly experience significant temporal and spatial variations of most meteorological elements. Since the watershed manager is most concerned with precipitation, its form, extent, amount and reliability, a detailed examination of this element will comprise much of Chapter 3. Since there are no detailed maps of precipitation for use in watershed management, the use of iso-hyetal techniques and water balance methods as employed in the Idaho (and other states) water inventory studies (Idaho Water Resources Board, 1968), and as advocated by Laycock (1978), will form the basis of the precipitation analysis in Chapter 3.

2.3.4 Hydrologic Analysis

A fundamental component of the problem analysis approach is a clear understanding of a region's water supply characteristics (Wilm and Dunford, 1941). The application of any management objective is illogical unless the water supply variations are fully understood, since the potential ramifications of each action would be unpredictable. Thus the objective of simple protection, as adopted by the Alberta government in its 'Policy for Resource Management of the Eastern Slopes' is ill advised since water supply/demand configurations are not complete for this region. Therefore, a detailed analysis of the water supply patterns for each region would help to clarify which potential watershed management objectives are realistically achievable and desireable. Such an analysis must consider the natural processes, streamflow and lake level variations, and the significance and extent of groundwater. Since the hydrology of the District is discussed in detail

in Chapter 4, only a brief synopsis of the methods used is related here.

The interpretation of natural runoff processes is often more easily understood in a qualitative sense than can be predicted quantitatively. Without a comprehensive data base comprising precipitation inputs, evapotranspiration losses and groundwater fluctuations, quantification of runoff values can be difficult. In the Kananaskis District, stream gauging stations have provided a variable record of streamflow for various sub-basin units within the watershed. Developing areal runoff patterns for each gauged sub-basin unit is easily achieved using conventional statistical measures. Explaining the runoff patterns requires an intuitive reasoning, supported by evidence from scientific research, of the effects which physiographic and vegetative factors influence the meteorologic elements. Laycock (1957a, 1961, 1966, 1973) has discussed the relationship between these factors and runoff with regard to watershed management for the Eastern Slopes. Much of the information presented in Chapter 1 on physical site descriptions and in Chapter 2 on watershed soils classification will be used to help explain the quantitative runoff values provided by the stream gauges.

The analysis of streamflow and lake level records will be an attempt to illustrate the differences in historical and contemporary patterns. Again the techniques for analysis of streamflow data are those developed in any text on hydrology, including among others, Chow (1964), Linsley et al. (1958), Barry and Chorley (1969) and Gray (1970). The emphasis of the analysis is not to focus on the techniques but rather on the explanations of the changes in regime which have occured and how these changes are reflected in evolving management strategies.

An analysis of groundwater systems is difficult, largely due to the extensive and relatively expensive data gathering networks required. In fact in many hydrologic models, the groundwater component is often the unknown quantity, to be predicted with the help of 'black box' methods (Gray, 1970). In mountain regions, groundwater information is often predicted using indirect methods, including information on rock type, vegetation distribution and poorly drained soils. In the Kananaskis District some research work has been conducted into a groundwater hydrologic budget (Stevenson, 1974) and when combined with a discussion of indirect information sources mentioned above, an appreciation of the extent and significance of groundwater distribution in the District can be gained.

The hydrologic analysis developed in Chapter 4 is part of a logical progression in the stages of a regional analysis. The climatic analysis in Chapter 3 uses the streamflow records as a basis for supplementing the precipitation record and as an aid in describing the spatial and temporal patterns of precipitation. With detailed precipitation and streamflow pattern information, a more viable and non-biased study of water management objectives can be made subject to the physical potential of the region.

Chapter 3

3.0 CLIMATE ANALYSIS

A climate analysis is important, because not only are the present variations in water supply better delineated, but also the potential for change in these supply patterns can be identified. For example, the identification of low precipitation areas in valleys with moderate forest cover and little runoff, would suggest that the potential for water yield increases through snow management or vegetation cutting would be minimal. Conversely, areas receiving high amounts of precipitation and moderate to dense forest cover, may have a potential for water yield increases, if that is the management objective. Since the physical expressions of the landscape have a significant effect on the distribution of certain climatic processes, a discussion of physiographic controls on meteorological elements will form the first part of Chapter 3. The remainder of the Chapter will contain an in-depth analysis of those climatic elements which affect precipitation, culminating in a description of the precipitation patterns of the District.

3.1 GEOGRAPHIC ASPECTS OF MACRO-CLIMATIC PATTERNS

3.1.1 Latitude

Latitude is the chief controlling factor in influencing the amount of solar radiation, and thus the length of daylight hours. In the Kananaskis District, there is a wide variation in daylight hours, from less than 8 hours in late December to more than 16 hours in late June (Lester, 1974). In a general sense, latitude also helps to define the length of the seasons, since the variations in

hours of daylight contribute strongly to cold winters, much warmer summers, and the short transitional periods characteristic of the region. Latitude also determines the nature and intensity of the low and high pressure systems that migrate across the region (Janz and Storr, 1977). The latitudinal belt of southwestern Alberta is near the mean location of the polar front, along which can be found eastward moving extratropical cyclones from the Gulf of Alaska (Lester, 1974). Associated with these pressure systems are the maritime polar (mP) air masses. These air masses have their source region over the North Pacific, are characteristically mild and moist and although partly de-hydrated are by far the most important source of moisture for the entire Eastern Slopes (Laycock, 1957a).

3.1.2 Continental Location

The continental location of southwestern Alberta also has a direct bearing on the climate of this region. The distance from large moderating bodies and the intervening mountain ranges are largely responsible for the 'continental' nature (cold winters, warm summers) of the climate (Janz and Storr, 1977). Longley (1972) using the Koppen classification system, has classified the climate of the Eastern Slopes as being Dfc, where 'D' indicates a cold snowforest climate with the average temperature of the warmest and coldest months above 10° C (50° F) and below -3° C (26.6° F) respectively. The 'f' term signifies precipitation in all months, while the 'c' term is a temperature subclassifier indicating that the mean temperature of the warmest month is below 22° C (71.6° F) and that there are less than four months with mean temperatures of 10° C (50° F) or more. Located adjacent to the prairies, the Eastern Slopes are subject to frequent incursions by continental polar (cP) air masses from the northern interior portions of the continent. These dry, cool to cold air masses penetrate the front

ranges through the major mountain passes and are responsible for depressing temperatures below average in any season. The interaction of cP with mP air masses is responsible for much of the frontal precipitation along the Eastern Slopes.

3.1.3 Intervening Mountain Ranges

The presence of the intervening mountain ranges west of the Eastern Slopes has a significant effect on the broad scale climatic patterns. These intervening ranges intercept some of the moisture carried by westerly winds, leaving the Rocky Mountains and the Eastern Slopes drier than they would be if the western ranges were absent (Janz and Storr, 1977). The absence of major relief features to the east allows for the movement of air masses from Hudson's Bay and the Gulf of Mexico, and cold, dry arctic air masses from the Beaufort Sea into the region, where they meet with those from the west in frontal uplift situations that contribute much to the precipitation of this area. The influence of these air masses on the inter-mountain valleys and ridges within the Eastern Slopes decreases from east to west due to air flow blocking ridges. This blocking process is reflected in the winter pattern of mean surface isotherms which tend to be aligned parallel to the mountain chain rather than along the parallels of latitude (Lester, 1974). As a result, the higher foothill areas and back range ridges often experience warm temperatures by virtue of their altitude and the density of the cold cP air mass. Perhaps the most dramatic effect of the mountians on the the climate of the Eastern Slopes is its influence on the Chinook - a warm, dry and gusty westerly flow of air which moderates temperatures over very short periods of time (Marsh, 1965). The Chinook occurs when strong westerly flow aloft responds to a progressively decreasing pressure gradient across the mountains. The relatively warm westerly winds are warmed further by compression and by the addition of the heat of condensation as they flow down the mountain slopes, thus enabling them to pick up moisture as they move into the lower valley

and foothill locations. Chinook like conditions may occur in any season, although they are most frequent and best defined in the cooler months of the year (Lester, 1974).

It is obvious from the foregoing discussion, that the mountains play a very important part in the climate of the Eastern Slopes. Temperature and precipitation variations on a spatial and temporal basis are due, in part, to the mountains' influence on the different air masses. Their characteristics will be useful in understanding those sections later in the thesis where there is discussion of the detailed climatic and water supply patterns in the Kananaskis District.

3.1.4 Air Mass Characteristics

There are basically four distinct air mass types which are found to influence the Eastern Slopes. The maritime polar (mP) air masses, described briefly above, are the dominant sources of moisture for the Eastern Slopes in any season. This is despite the fact that they lose much of their moisture while crossing the intervening mountain ranges. The back range areas near the Continental Divide receive the greatest amounts of precipitation from this air, largely as winter snowfall (Laycock, 1957b, 1961, 1965). Most of this precipitation is due to orographic uplift, and carry over effects from ranges further west, while precipitation away from the Divide areas in the intermountain valleys often occurs due to frontal formations. This occurs when the relatively warm moist mP air overrides cold, dry continental polar (cP) air that intrudes into the area. Orographic uplift of mP air is also responsible for much of the precipitation on the higher mountains of the easternmost region of the front ranges (Laycock, 1957b). On a seasonal basis, most of the spring, summer and fall rainfall is also received from mP air, however the largest amounts are usually received in

the spring and early summer when cyclonic passage is most frequent. In summer convectional showers are also common as air is heated on south facing slopes, producing some local rain showers with subsequent uplift.

The cP air masses are characteristically dry and, depending on the season, either cool or cold. While they are responsible for the dry conditions during the summer, it is during the winter months when they are most noticeable, often dropping temperatures markedly. These air masses seldom provide moisture themselves but they do interact with mP air masses resulting in mainly frontal precipitation with some orographic addition especially on the northeast facing front range and foothill ridges (Laycock, 1957b).

Maritime tropical (mT) air masses from the Gulf Coast regions of the United States bring hot and moist air into the region. These air masses infrequently enter the region but when present are responsible for intense rains of varying duration. The effect of these air masses is most strongly felt in the southern front range and foothill areas since conditions are seldom conducive for this air mass to move much further north or inland (Laycock, 1965).

Continental tropical (cT) air masses originate in the dry, interior regions of southwestern United States and occasionally find their way north in the summer and early fall period. Being characteristically hot and dry, they are responsible for high temperatures, low precipitation and high evapotranspiration (Laycock, 1957b).

3.2 PHYSIOGRAPHIC INFLUENCES ON SELECTED CLIMATIC ELEMENTS

3.2.1 Radiation

Radiation is the most important of the meteorological elements. It is the source of power which drives atmospheric circulation, provides the energy for snowmelt and evaporation, and is one of the most important factors governing the growth of vegetation. Unfortunately, radiation is a very complex element, rather difficult and more expensive to measure than most. As a result, information on radiation tends to be scarce. Only one station, in Marmot Creek in the Kananaskis District provides radiation data, while two sunshine recorders have been maintained in nearby Banff and Yoho National Parks for several years, and one recorder was installed at the Kananaskis Centre for Environmental Research [formerly known as the Kananaskis Environmental Sciences Centre, (i.e. E.S.C.)], where an intermittent record of observation is available.

Incoming short-wave radiation at the top of the atmosphere above the Kananaskis District varies from less than 200 langleys/day in December and January, to between 900 and 1,000 langleys/day in May, June and July (Ferguson et al, 1971). Some of this is absorbed and reflected by clouds and small particles in the atmosphere, and by reflective surfaces on the earth, while the remainder reaches the earth. The variability of effective short-wave radiation at Marmot Creek, on a seasonal basis, taking slope into account, can be seen in Figures 3.2a and 3.2b.

Maximum daily radiation over the basin occurs on or near the summer solstice of June 21, with values ranging from less than 700 langleys/day to over 950 langleys/day. A definite valley-ridge shading pattern is evident, with the maxima occurring on south facing

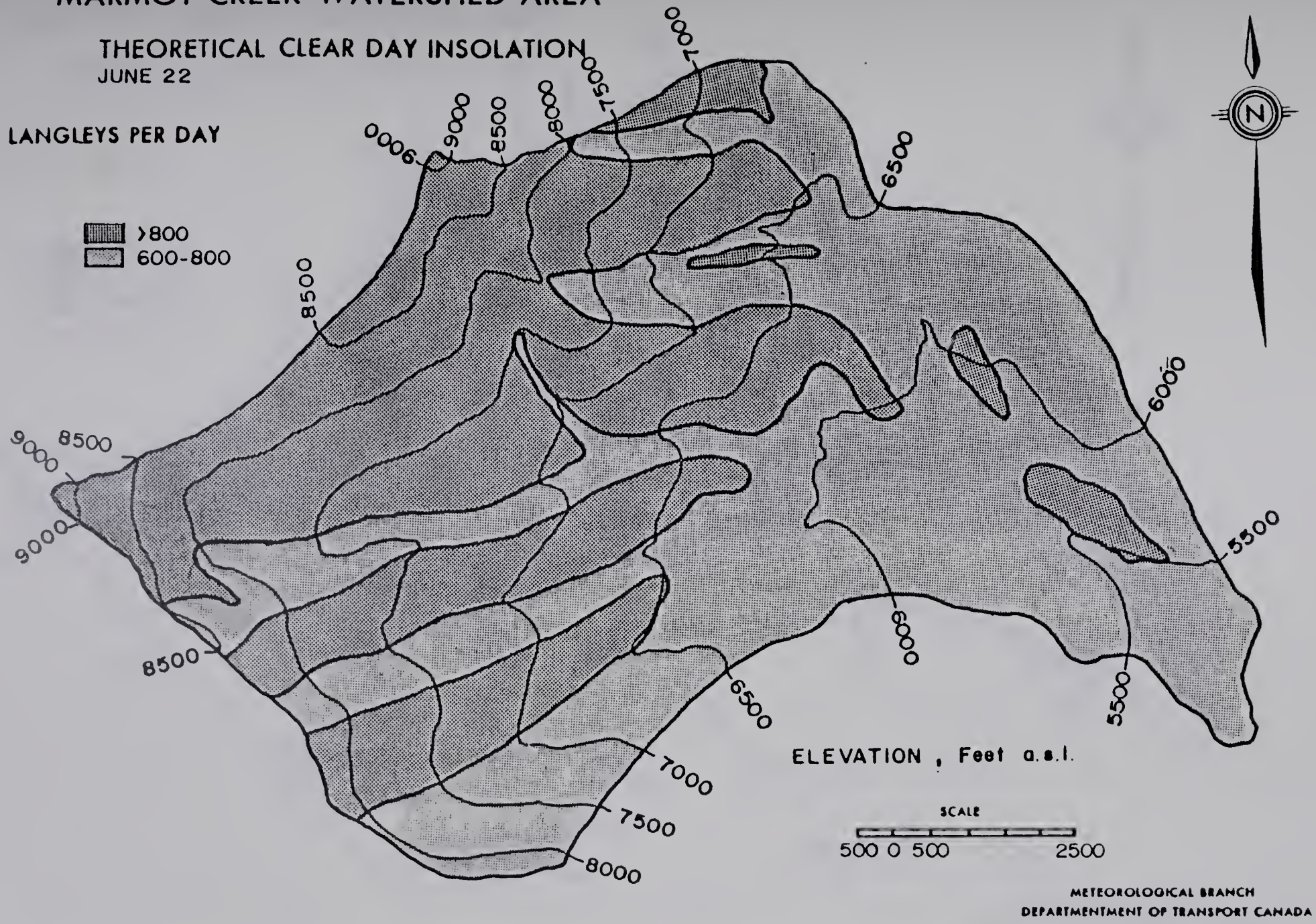


Figure 3.2a Variability of Clear Sky Effective Incoming Short-Wave Radiation at Marmot Creek

(AFTER: Ferguson et al, 1971)

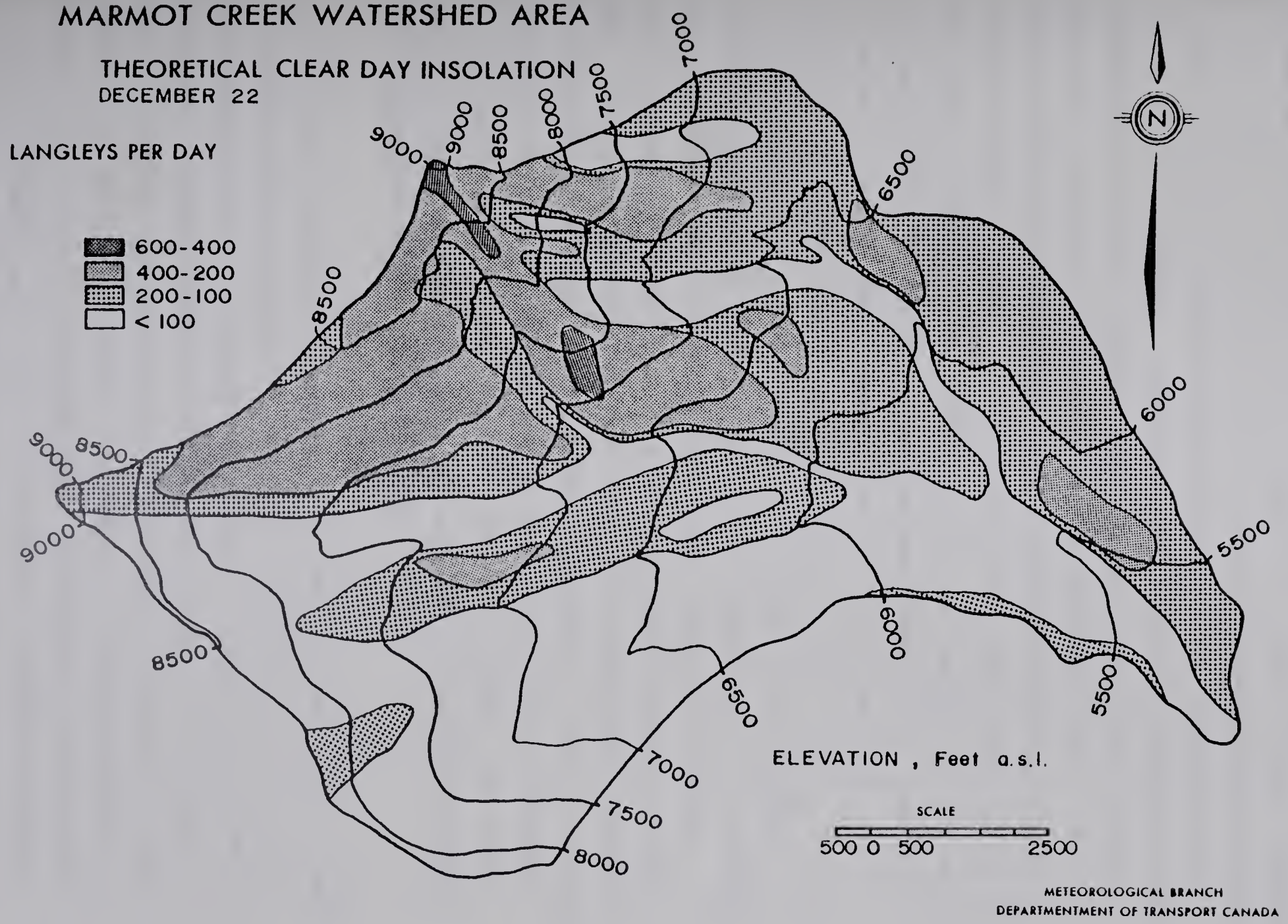


Figure 3.2b Variability of Clear Sky Effective Incoming Short-Wave Radiation at Marmot Creek

(AFTER: Ferguson et al, 1971)

slopes. Higher radiation values tend to occur at higher elevations where atmospheric attenuation is relatively small, and where there are steeper south facing slopes having fewer shadow effects (Ferguson, et. al., 1971). The pattern for the winter solstice around December 21, shows radiation values ranging from less than 50 langleys/day to over 400 langleys/day. Radiation values for the spring and fall equinoxes are similar, although March 21 exhibits slightly higher maxima due, in part, to reflected amounts from snow cover. The effect of mountain shadows and of season on net radiation has been examined by Storr (1972). Figure 3.2c shows curves representing two clear days at Marmot Creek. The mountains to the east of the valley are considerably further away from the measurement site than those to the west, so the sharp jump at sunrise is not nearly as pronounced as the sharp drop at sunset (Janz and Storr, 1977). It is obvious that in deep, narrow valleys the effect of topographic shading by surrounding ridges would be more pronounced. The annual cycle of average daily incoming short-wave radiation at Marmot Creek is shown in Figure 3.2d with 95% confidence limits for each month. The major features of the curve are the May-June 'shoulder' the July maximum and the December-January minimum. The first feature corresponds with marked cloudiness in June reflecting the passage of lows which bring cloudy, moist air into the region. The other two are correlated with the angle of incidence of the sun combined with topographic effects (Powell, 1973).

The use of sunshine recorders as a means for measuring incoming short-wave radiation can be found at two sites east of the Divide in mountain terrain. Although the periods of record are variable in length and sometimes quite irregular, the patterns which emerge are similar to those described above. Data for the duration of bright sunshine are available for Banff townsite, and the Environmental Sciences Centre (E.S.C) at Kananaskis. These data, for the period of record available, are compared with those of Calgary in Table 3.2a. Although a higher frequency of cloudiness is undoubtedly a factor in the values for Banff and E.S.C., a low angle of in-

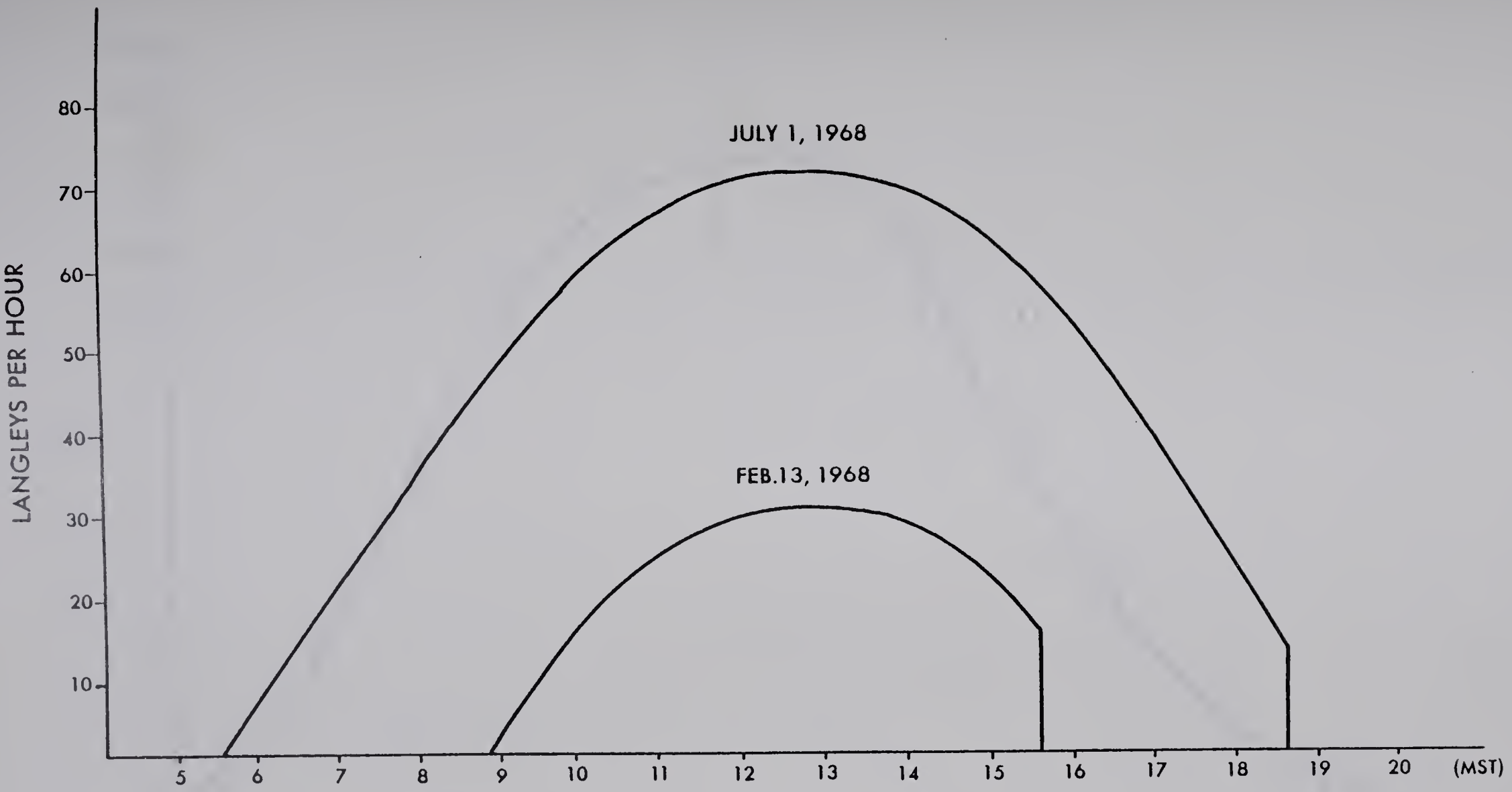


Figure 3.2c Effect of Season and Topographic Shading on Net Radiation at Marmot Creek

(AFTER: Janz and Storr, 1977)



Figure 3.2d Mean Daily K ↓ at Marmot Creek with 95% Confidence Limits

TABLE 3.2a

Average Number of Hours of Bright Sunlight

Station	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEPT	OCT	NOV	DEC	ANNUAL	PERIOD
Calgary	99	121	156	196	237	240	317	278	188	166	116	94	2208	1941-1970
Banff	59	93	126	160	200	207	255	214	171	130	82	42	1739	1941-1970
ESC*	59_6	122_6	163_6	156_3	217_5	239_6	274_7	232_6	190_5	171_5	85_8	47_6	1955	1968-1969 1971-1978

*Subscripted figures on ESC data indicate years of record.
ESC - Environmental Sciences Centre, Kananaskis

Source: Atmospheric Environment Service, 1968-1978

cidence combined with topographic interference are the main reasons, particularly in winter, for the differences. Since the E.S.C. data are very inconsistent, no comparisons can be made between them and the Banff data.

In summary, the data available suggest a strong relationship between measurable radiation and topographic characteristics, on both a daily and seasonal basis, in a mountain environment. The effect of seasonal cyclonic movements over the mountains is also noted, however the transient and unstable nature of these systems precludes any quantitative assessment of their effects. The importance of radiation data in making management decisions related to recreation has been noted by Janz and Storr (1977). In terms of watershed planning, the effects of radiation on snow, especially during the snowmelt runoff period, would be significant enough to influence those practices which sought to manipulate the amount and timing of runoff (Storr, 1972).

3.2.2 Temperature

Air temperature in the Eastern Slopes is controlled by three main factors, the radiation cycle, the duration and characteristics of different air masses, and elevation. The first two are responsible for some rather large time variations in temperature, whereas elevation contributes to significant areal or place to place variations (Janz and Storr, 1977).

In their study of the Contiguous Mountain Parks, Janz and Storr (1977) found a number of interesting relationships. A review of temperature data for selected stations showed that the annual temperature range east of the Continental Divide exceeded that found west of the divide. A further look at the extreme minimum and

extreme maximum temperatures which occur in winter are also, respectively lower and higher east of the Divide. They attribute the extreme low temperatures to periods when stable continental polar (cP) air stagnates over the Eastern Slopes and much of the Prairies. Similarly, the extreme maxima in winter are higher east of the Divide due to the influx of warm, dry Chinook air. Powell (1973) noted that the alternation of these two distinct air mass types was responsible for the very large extremes in winter temperatures that are experienced in southwestern Alberta. The extent to which these events can produce rapid changes in temperature over short time periods is evident in that the E.S.C. station in the Kananaskis recorded a temperature range of 60°C(108° F) during the month of December, 1968 (Powell, 1973). There are significant differences however in the effectiveness and duration which the same air mass will have over the entire East Slopes region. For example, Longley (1967b) using narrowly defined temperature criteria, found that Kananaskis experienced, on the average, 29 Chinook days, which was two more than Calgary and 19 more than Banff suggesting a higher percentage along the lee slope of the front ranges and higher foothill areas. Recent studies by Lester (1976) and Golding (1978) suggest that there is no evidence that the frequency of Chinooks decreases from south to north or from back range to foothill areas. It was also noted that Longleys' (1967b) temperature criteria are not flexible enough to recognize variations in the strength and effectiveness of individual Chinook events. The effectiveness of a Chinook to significantly alter temperature has been shown by MacHattie (1963), who recorded a change of 22.2° C (40° F) in a two hour period. In essence then, rather large and frequent temperature variations are characteristic of the Eastern Slopes, particularly in the winter months, due to changes in the air masses affecting the regions. Generally there is less variation in summer temperatures since net solar radiation levels are higher and the effect of Chinook winds combined with other air mass shifts are more subdued.

Even without detailed meteorological measurements, there are obvious indicators that a temperature-elevation relationship exists. One example is that of vegetation zonation, where the sequence is from grassland and mixed deciduous forest in the valley bottoms to scattered krumholtz communities where stunted alpine fir gives way to hardy lichens at the higher elevations. Perhaps a better indicator is the presence of glacier ice and permanent snowfields high above the treeline, and the existence of snowcovers on the loftiest peaks, even in summer. Aside from the descriptive indicators, it is known that as air is lifted and expands it cools, and as a result, increasing elevation normally results in a decrease in temperature. In the free atmosphere, air temperature decreases about 5.5° C/km (3.5° F/1000 ft.) on the average, but there are many exceptions and large deviations from this average. While factors such as slope and aspect influence the amount and duration of radiation which comes into contact with air near the ground, other controls, including air pressure, affect the movement of air. For example, cold air becomes more dense as it cools making it heavier than warm air, and at the same pressure the cold air would begin to move downslope. This can result in a reversal of the normal expected situations, with cold air occupying the valley bottoms and the higher slopes actually increasing in temperature with elevation. Because this trend opposes normal conditions these cases are called temperature inversions. The normal diurnal cycle of air temperature, with a minimum shortly after sunrise and a maximum in mid or late afternoon is progressively dampened with elevation in the free atmosphere. Similarily, it is found that the temperature range (the difference between the maximum and minimum) becomes progressively smaller with elevation at surface sites in mountainous areas (Janz and Storr, 1977).

While temperature data for many of the higher back range areas is inadequate, there are sufficient data for most of the valleys and lower slopes with which to develop patterns for these areas. In the Kananaskis District temperature data exist for Marmot Creek, E.S.C., Boundary Ranger Station (B.R.S.), and two forestry lookout stations, Pigeon Lookout (PLO), and Kananaskis Lookout (KLO), (see Figure 3.2e). Table 3.2b is a list of the monthly, annual mean and extreme temperatures for the five stations using available data. At first glance it would appear that altitude effect is apparent for the mean maximum temperatures in the warmer months. Lester (1974) suggests that the decrease in mean maximum temperature for the month of July by the KLO, Marmot and ESC. stations is approximately -0.65° C per 100 M (-0.36° F per 100 ft.). Janz and Storr (1977), in attempting to show a temperature-elevation relationship for the southeastern part of Banff National Park used data from Marmot Creek and the Kananaskis E.S.C.. The results depicted in Figure 3.2f for the months of January and July show that the linear best-fit lines gradually converge with height for both months, confirming the diminishing temperature range with elevation. While it may be argued that a temperature-elevation approach is far too simplistic a technique for areal extrapolation, elevation is the principal control in the determination of average temperatures (Janz and Storr, 1977).

The temperature variations which occur on a seasonal and elevational basis are of significance to the watershed manager for several reasons. Temperature plays an important role in the water balance of an area by influencing the rate and amount of moisture evapotranspired from vegetated, soil and standing water areas. The rate of areal decline of spring snowpacks is determined largely by temperature (also, aspect, slope, exposure). Effective snowpack management for yield or regime purposes would require knowledge of the spatial and temporal temperature variations to optimize snowmelt runoff at desired rates and volumes. Temperature variations are

Figure 3.2e
Temperature Recording Stations

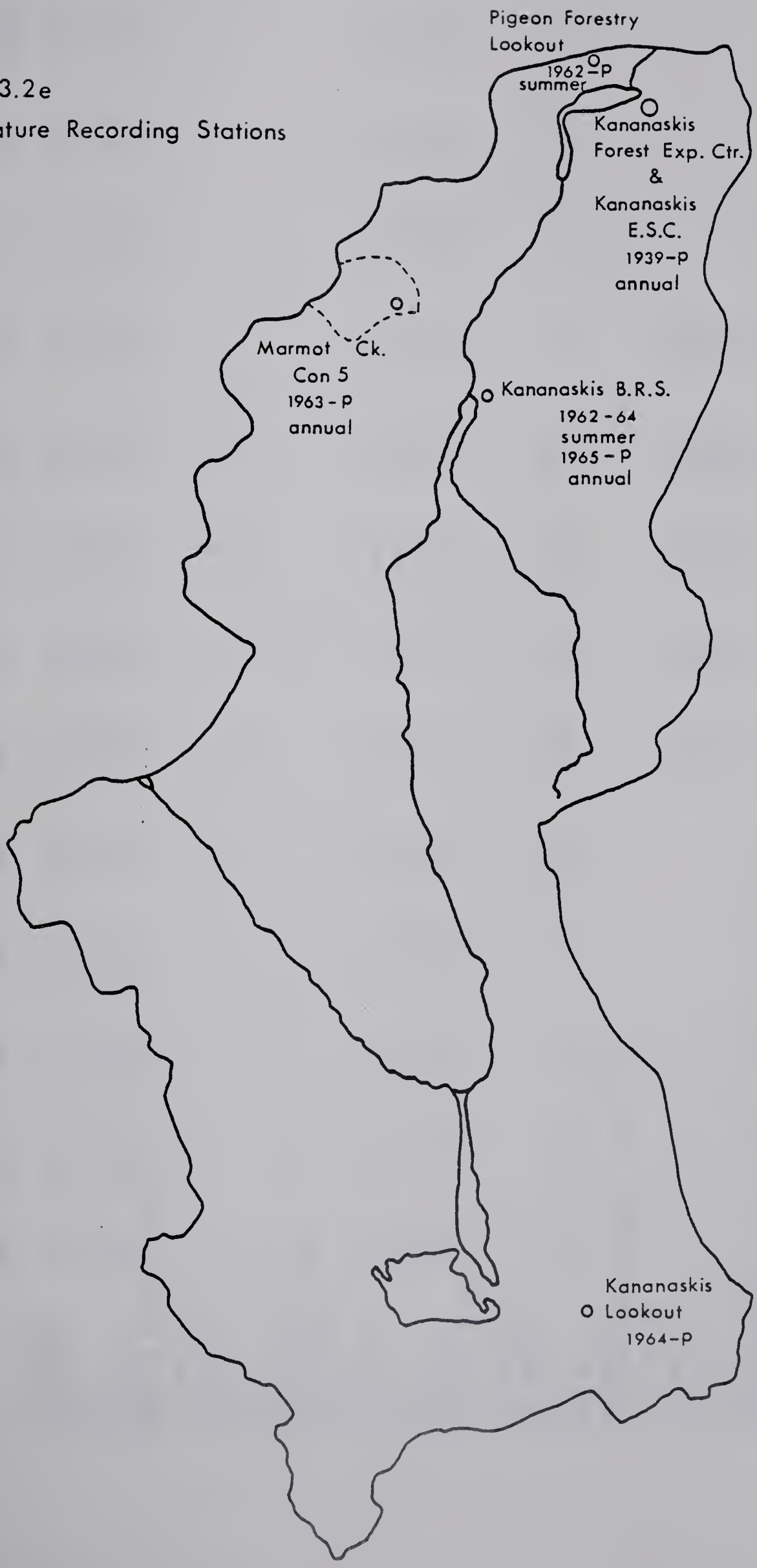


TABLE 3.2b
Monthly and Annual Mean and Extreme Temperatures (0^{o} C) at ESC, PLO, MARMOT (CON 5), BRS AND KLO

	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEPT	OCT	NOV	DEC	ANNUAL
ESC (1380 M)													
Extreme Max.	+17.2	+16.1	+18.3	+23.9	+27.8	+31.1	+33.9	+33.3	+30.0	+27.2	+18.9	+16.1	+33.9
Mean Max.	- 3.3	+ 0.6	+ 2.4	+ 8.2	+13.8	+17.4	+22.1	+20.7	+16.3	+11.3	+ 3.6	- 0.3	+ 9.4
Mean	- 9.7	- 6.0	- 4.2	+ 1.8	+ 7.1	+10.7	+14.1	+13.1	+ 9.2	+ 5.0	- 2.3	- 6.1	+ 2.7
Mean Min.	-16.0	-12.7	-10.8	- 4.5	+ 0.3	+ 3.8	+ 6.1	+ 5.5	+ 2.1	- 1.4	- 8.2	-11.9	- 3.9
Extreme Min.	-45.6	-41.1	-40.6	-31.1	-21.7	- 5.6	- 1.1	- 2.2	- 9.4	-22.2	-35.6	-42.2	-45.6
PERIOD OF RECORD: 1941 - 1970													
PLO (1830 M)													
Extreme Max.													
Mean Max.					+ 8.3	+11.1	+15.6	+13.9	+ 8.9				
Mean						8.9	13.3	12.2					
Mean Min.													
Extreme Min.													
ESTIMATED FOR PERIOD: 1931 - 1960													
MARMOT (CON 5) (1760 M)													
Extreme Max.	+ 9.4	+13.3	+13.9	+18.3	+23.9	+26.7	+26.7	+30.0	+27.2	+22.2	+10.0	+10.0	+30.0
Mean Max.	- 7.9	- 0.1	+ 0.4	+ 4.6	+10.2	+14.8	+18.9	+19.6	+12.8	+ 8.7	- 0.2	- 6.4	+ 6.1
Mean	-13.0	- 5.7	- 5.6	- 1.0	+ 4.1	+ 8.5	+11.7	+12.1	+ 6.5	+ 1.5	- 5.2	-11.3	+ 0.2
Mean Min.	-18.1	-11.4	-11.7	- 6.6	- 2.1	+ 2.2	+ 4.4	+ 4.6	+ 0.2	- 4.1	-10.2	-16.3	- 5.8
Extreme Min.	-37.8	-28.9	-30.0	-17.8	-12.2	- 3.9	- 4.4	- 2.2	-17.4	-23.3	-31.7	-40.0	-40.0
PERIOD OF RECORD: 1963 - 1972													
BRS (1465 M)													
Extreme Max.													
Mean Max.					+15.6	+18.3	+23.3	+21.7	+11.1				
Mean	-11.1	- 8.9	- 6.1	0.6	6.4	10.0	13.4	12.8	8.9	4.4	- 3.9	- 8.3	1.5
Mean Min.													
Extreme Min.													
ESTIMATED FOR THE PERIOD: 1931 - 1960													
KLO (2070 M)													
Extreme Max.						+25.0	+25.6	+30.0	+26.7	+20.0			
Mean Max.						+12.4	+17.8	+16.1	+11.0	+ 4.9			
Mean						+ 7.9	+12.1	+10.8	+ 6.6	+ 0.8			
Mean Min.						+ 3.1	+ 6.4	+ 5.6	+ 2.1	- 3.4			
Extreme Min.						- 4.4	- 1.1	- 6.1	-11.1	-11.7			
PERIOD OF RECORD: 1964 - 1970													

$^{o}F = 1.8 (^{o}C + 40) - 40$

Source: Environment Canada, 1971, 1972

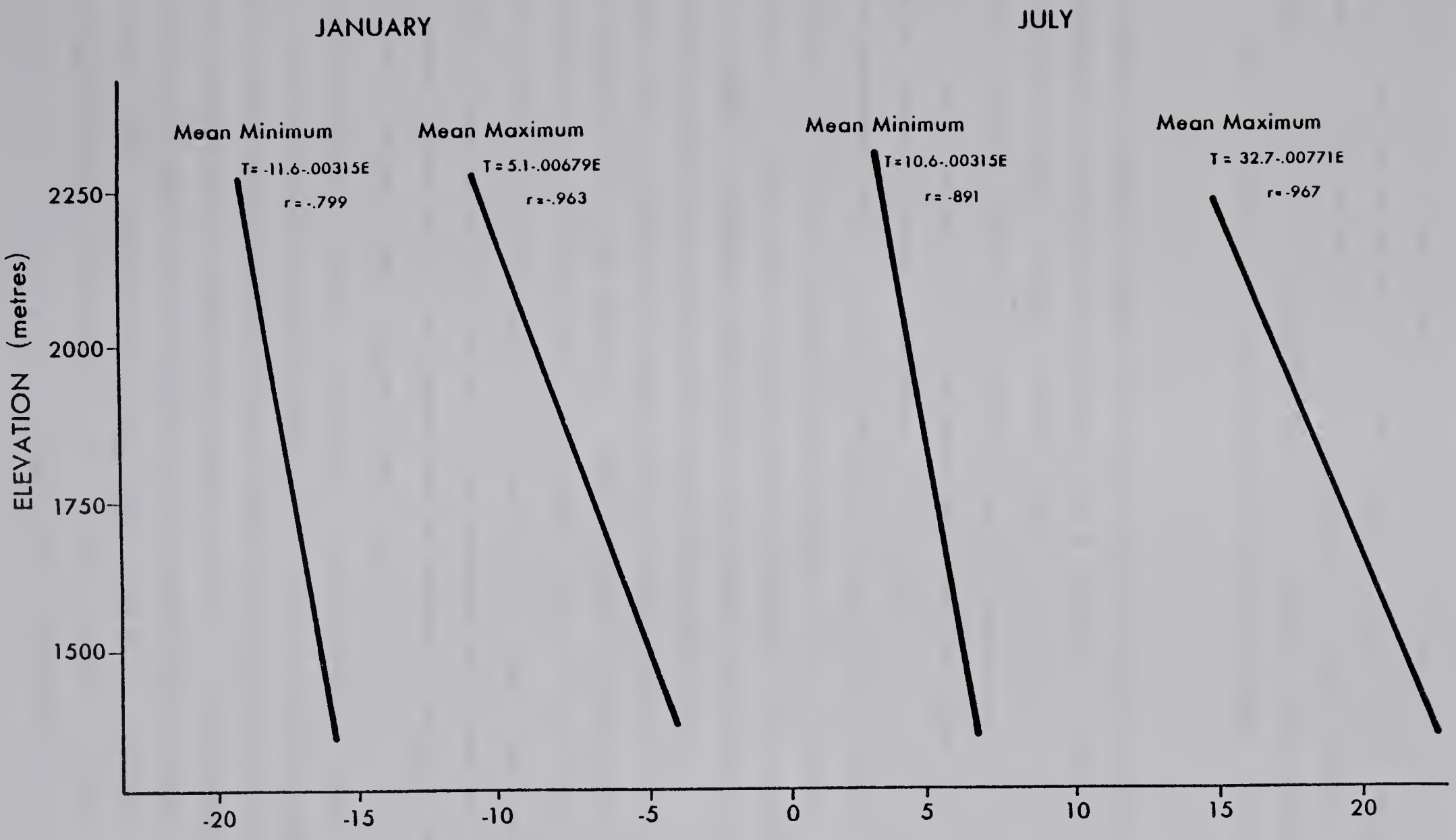


Figure 3.2f Elevation-Temperature Relationship (Marmot Creek Area)

(AFTER: Janz and Storr, 1977)

responsible for the freeze/thaw cycles which determine the rate and amount of detention storage in coarse colluvial materials of snowmelt runoff. This temperature plays a vital role in the basin hydrologic cycle and an understanding of the regional and elevational patterns can be useful in interpreting precipitation/runoff relationships.

A number of general observations about temperature variations in the Kananaskis District can be made from a variety of research and literature sources. Powell (1973) noted that there was less variation in summer temperatures than in winter temperatures, but at higher elevations this reduction was less. On the other hand, the diurnal range in temperature shows an increase from winter to summer in agreement with a general decrease in advective influences and a takeover of local heating effects (Lester, 1974). In his examination of diurnal summer temperatures, MacHattie (1970) found that at the time of maximum temperature, the lapse rate along the slopes between the valley bottom and about 1830 metres a.s.l. (6000 feet a.s.l.) tended to be less than the adiabatic rate of 1^{o} C per 100 M (5.5^{o} F per 100 ft.). This resulted in inversions of 3^{o} to 6^{o} C (5^{o} to 10^{o} F) on a clear summer night in the lowest 90 metres (300 feet) of the valley. In an earlier study, Munn and Storr (1967) found that differences in the average daily maximum and minimum temperatures during the summer months between the upper and lower slopes of Marmot Creek varied from 6^{o} to 9^{o} C (10^{o} to 15^{o} F). On a purely descriptive basis a comparison of mean monthly temperatures of all Kananaskis stations show that E.S.C. has warmer summer months than Kananaskis Boundary Ranger Station (BRS) by about 0.5^{o} C (1^{o} F), and warmer winter months by as much as 4^{o} C (7^{o} F) (Powell, 1973). As well, comparisons of mean monthly temperatures between Pigeon Lookout (PLO), Kananaskis Lookout (KLO) and E.S.C., show July and August temperatures about 0.5^{o} C (1^{o} F) and 2^{o} C (4^{o} F) cooler respectively. Late spring and early fall temperatures for

KLO show differences of between 2° and 4° C (4° and 8° F) from E.S.C. (see Figure 3.2g). Unfortunately the forestry lookout stations are only manned during the fire season and therefore no data are available for the winter months.

The discussion to this point has been based upon data from the northern part of the district, much of it from valley and lower slope locations. Only one station, KLO, located in the southern part of the district adjacent to the Kananaskis Lakes, provides information on temperatures and then only for a short period of time. Using the temperature profiles in Figure 3.2f, it is possible to interpolate values for those elevations below 2500 metres a.s.l. (7000 ft. a.s.l.) with reasonable accuracy. Extrapolation of values beyond the 2500 metres a.s.l. (7000 metres a.s.l.) level would require more information concerning physiographic characteristics. In their analysis of temperature-elevation relationships for the mountain parks, Janz and Storr (1977) suggest that the given profiles should yield a mean monthly maximum to within 2° C for any locality within the parks. Maxima for localities situated near glaciers or permanent snowfields, usually found along the Continental Divide and the higher back range north facing slopes, would likely be from 3° to 5° C (6° to 10° F) lower. The mean minimum profiles for January, while providing good estimates for some areas, might provide very poor estimates for other areas particularly those localities influenced by glaciers, snowfields or frost hollows, and therefore this information should be used with caution.

In summary, there is evidence for a strong temperature-elevation relationship. However, departures from the normal situation are common as inversions during both summer and winter are experienced. Other factors such as snowfields, topographic anomolies, aspect, air mass characteristics and season also influence the temperature profile for any one time at any one place. Research has indicated

TEMPERATURE PROFILES KANANASKIS REGION

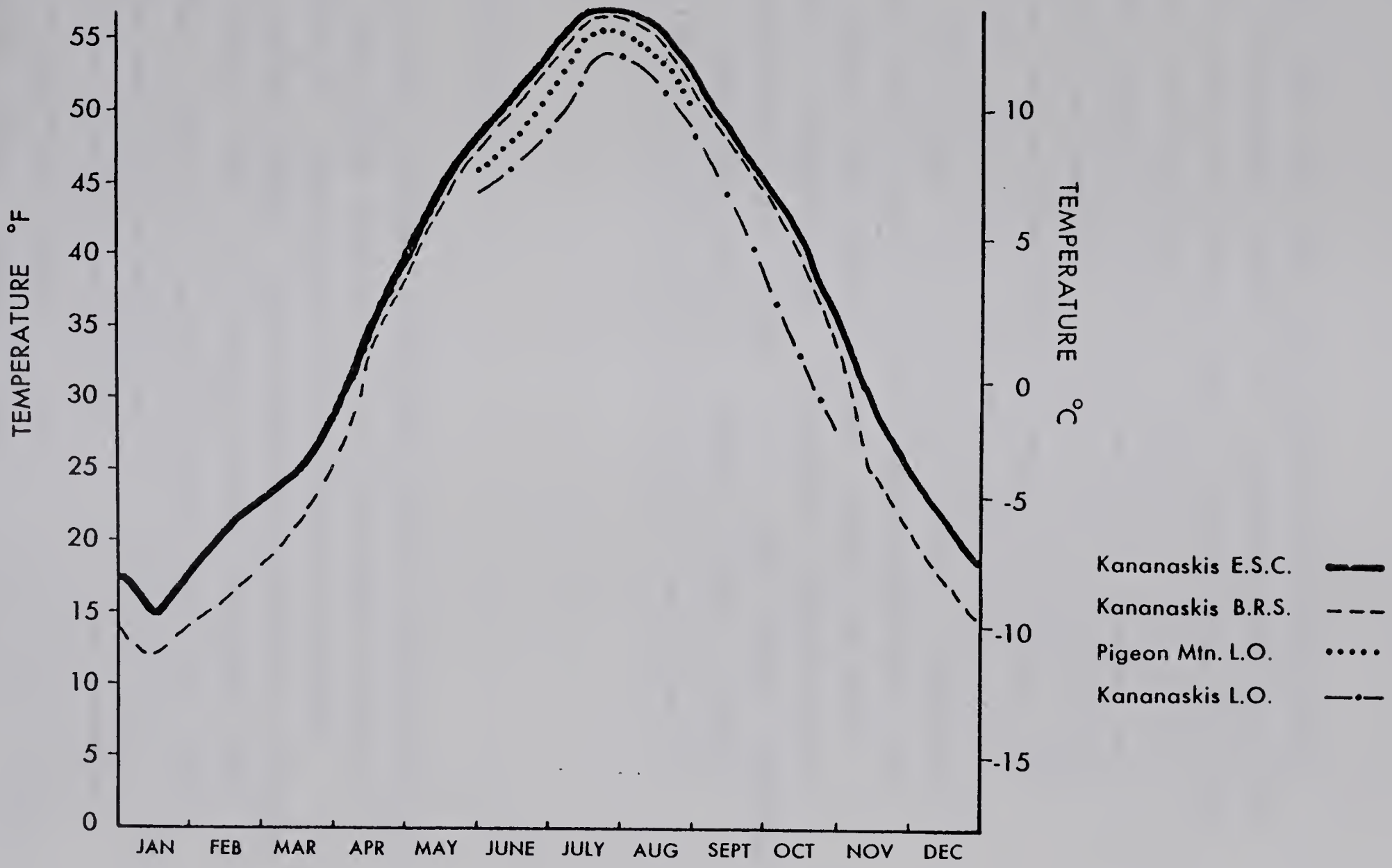
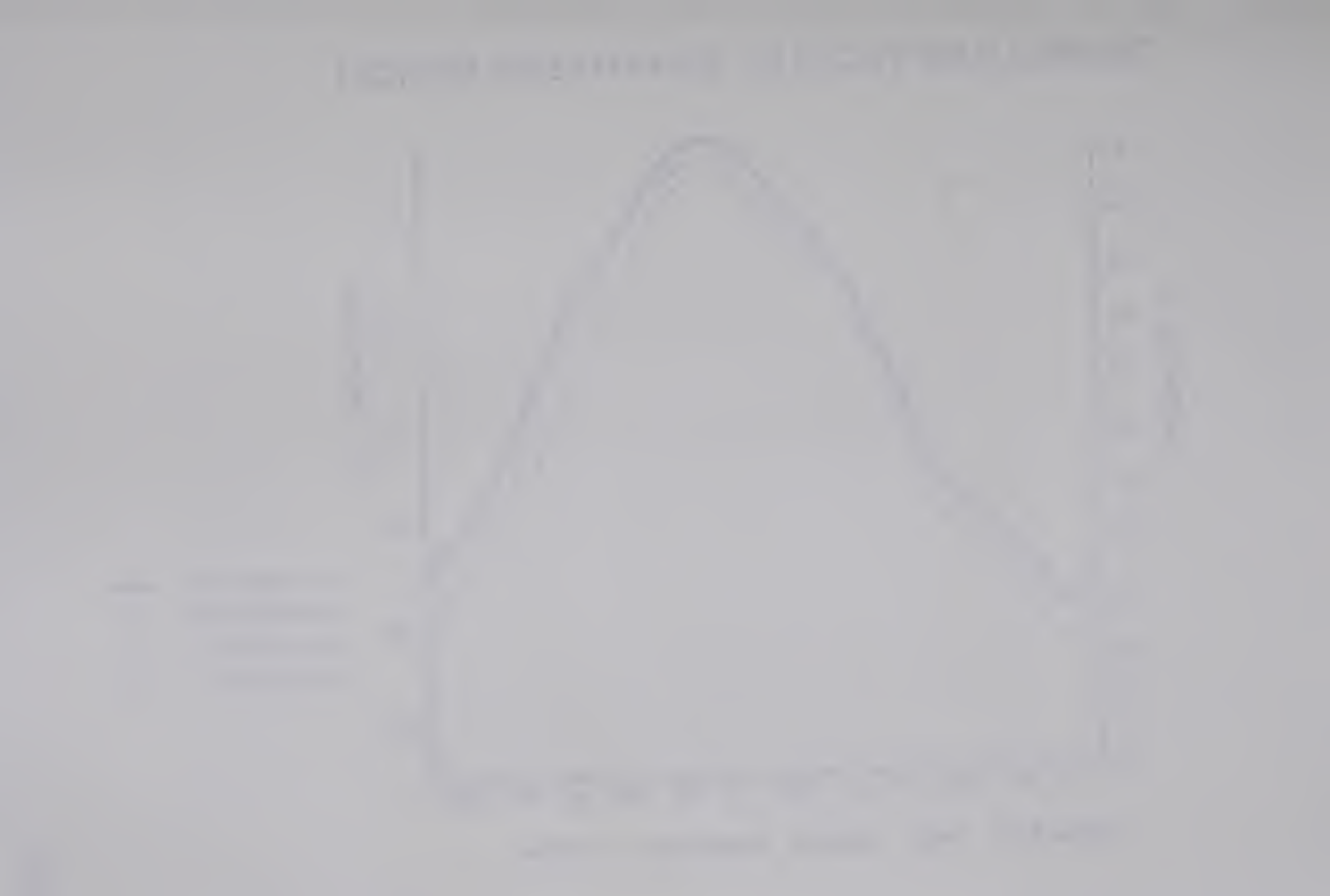


Figure 3.2g Mean Monthy Temperature Curves



(MacHattie, 1963, 1970) that, while temperatures may be quite variable in mountainous regions due to inversions which may last from hours to days, very rapid changes in temperatures have been experienced in the Kananaskis due to influxes of warm Chinook winds. The influence of these rapid temperature changes, and of inversions, on evaporation of snowpack and of soil moisture supplies has received some attention (Bergen and Swanson, 1964; Golding, 1977b, 1978; Louie, 1977; Marsh, 1965; Storr, 1974a). Certainly, the seasonal and elevational influence of temperature on precipitation affects, not only the evapotranspiration component of the hydrologic cycle, but also the rate and areal distribution of snowmelt runoff. Any attempt to manage the inputs of precipitation by increasing direct runoff through vegetation removal, or increasing snowpack for delayed release to streams must take into account the spatial and temporal variations in temperature.

3.2.3 Precipitation

The problem of adequately measuring values of precipitation is difficult under normal conditions, but in mountainous regions it is especially so. The patterns of precipitation in mountain areas are not well mapped, largely because these areas are sparsely settled (Laycock, 1978). The irregular nature of mountain topography makes it difficult to establish patterns throughout large areas, since precipitation amounts can vary considerably over short distances. Detailed networks of instruments are expensive to set up and maintain, therefore estimates of precipitation are usually based on amounts received in valley stations which are more accessable. Janz and Storr (1977), and Laycock (1978) have commented on the potential inaccuracies when valley results are used to estimate mountain precipitation.

The principle that precipitation increases with increasing elevation is generally accepted, and it has been suspected for some time that it also holds true in the Rocky Mountains. However, most of the precipitation maps produced for the Rocky Mountains have been inaccurate or conservative. The various editions of the Atlas of Canada largely ignored the precipitation of upland areas. For example, the 1957 edition displays a very generalized isoline pattern. Excessive attention to the low precipitation of Jasper and other mountain valley locations resulted in unrealistic mapping patterns relative to topography (Laycock, 1978). A number of attempts at accurate mapping have been made, but many of these have not been widely used. Several maps of precipitation of the Eastern Slopes have been based in part upon water balance calculations (Laycock, 1957b, 1967, 1978). The recent precipitation maps of the Rocky Mountain Parks, compiled for the Department of Indian and Northern Affairs, Parks Canada, by Environmental Canada (Janz and Storr, 1977) depict patterns based on physiographic and elevational information. Topographic information has also been used to an advantage in the various framework studies in the Western United States. For example, the mapping porcedures adopted by the Idaho Water Resources Board in its development of a State Water Plan includes the use of physiographically adjusted climatologic data, combined with information from stream gauging stations (Idaho Water Resources Board, 1968). Recent (1973) efforts by the Atlas of Canada to produce better precipitation maps for the mountain region have met with some success. This is due largely to an attempt to show better continuity in Alberta with patterns in British Columbia, where topographic adjustments in isohyetal mapping are more widely used (Laycock, 1978).

Attempts at qualifying the exact nature of the precipitation/elevation relationship have provided some interesting results and examples are available from Ferguson and Storr (1969), Storr and Ferguson (1972), Storr and Golding (1976), Poliquin and Hanson (1973), and Janz and Storr (1977). Storr and Ferguson (1972) analyzed

Marmot Creek data and developed the following regression:

$$P = -415.9 + .636E$$

where P is the average annual precipitation in millimetres and E is the elevation in metres.

Assuming that the equation represents a linear relationship, the actual calculated increase is approximately 64mm/100M (7.4 in./1000 ft). This value coincides quite closely with that of Poliquin and Hanson (1973), who, using similar stations in the Kananaskis Valley, calculated an average of 66 mm/100 M (7.8 in./1000 ft.). In their study of the Mountain National Parks, Janz and Storr (1977) calculated equations of average annual precipitation versus elevation for 30 storage gauges in and adjacent to the parks. Figure 3.2h illustrates the results. From this analysis there are two distinct types of stations, those that are dry and those that are not, and two distinct rates of increase. The author's suggest that the dry stations are those whose position relative to local mountain barriers protects them from both easterly and westerly upslope conditions, whereas, the other stations are more exposed to these conditions. However, other factors such as distance from the Divide and front ranges, and local divergence and convergence patterns in air flow would complicate the actual patterns.

Precipitation varies with elevation, not only in amount but also in form. A variety of sources exist which document that more precipitation in the form of snow falls at higher elevations than in valley bottoms (Ferguson and Storr, 1969; Golding, 1974; Janz, 1977; Janz and Storr, 1977; Laycock, 1954; 1957b, 1967; Poliquin and Hanson, 1973; Powell, 1973; Storr, 1967; Storr and Ferguson, 1972; Storr and Golding, 1976). As an example, Janz and Storr (1977) plotted the percentage of total precipitation

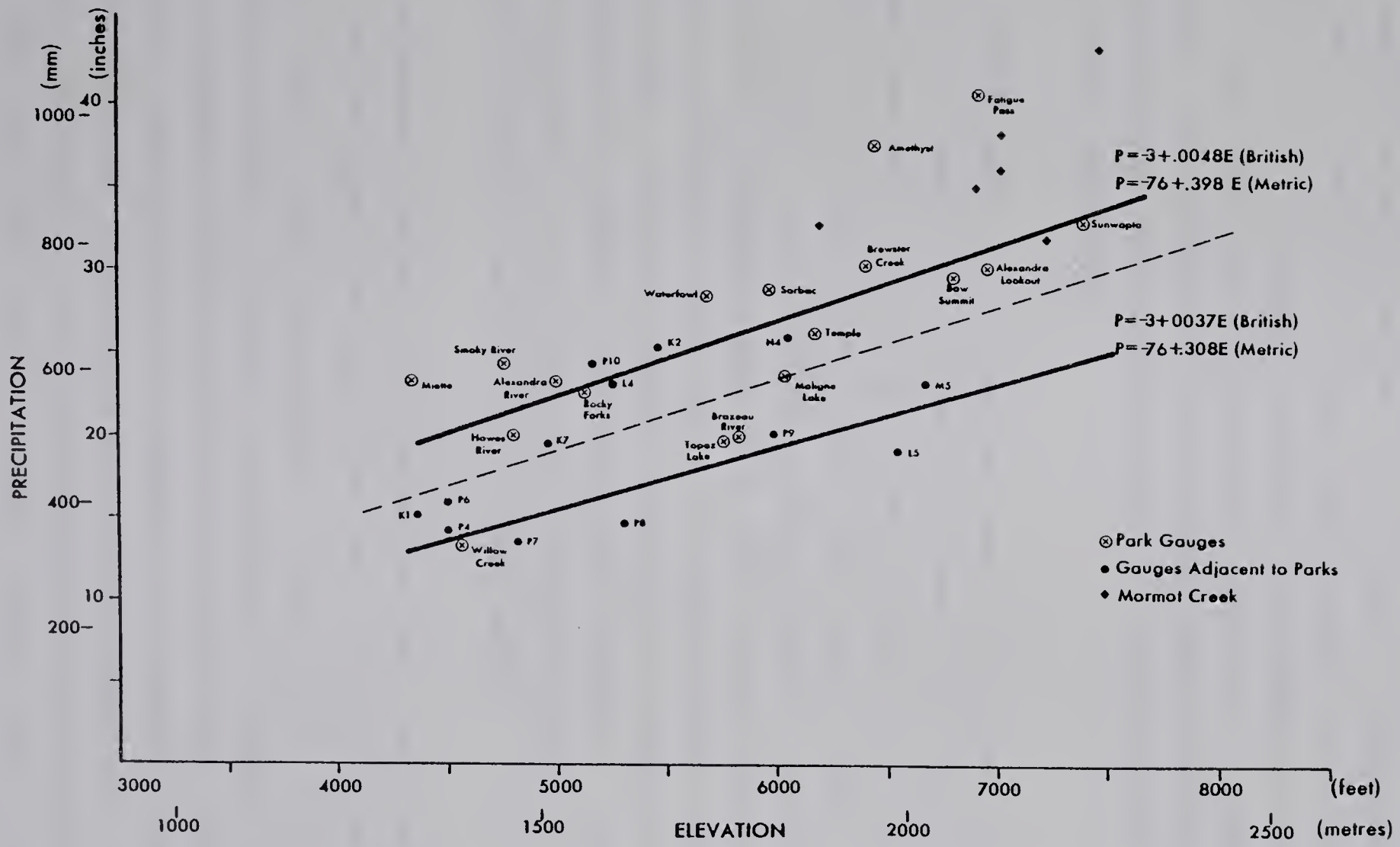


Figure 3.2h Average Annual Precipitation-Elevation Relationship in and Adjacent to the Mountain National Parks

Note: Stations East of Continental Divide Only

(AFTER: Janz and Storr, 1977)

falling as snow against elevation for a dozen stations in the Mountain National Parks. The results shown in Figure 3.2i provide only a rough quantitative idea as to the relative amounts of rainfall and snowfall at any elevation. The transfer of these results to other areas of the Eastern Slopes should be done with caution since there are too few points with which to confidently construct a best-fit line. Also, local and regional variations in topography result in some very obvious non-linear relationships for some of the stations depicted, and it is reasonable to assume that this would be the case elsewhere.

For the Kananaskis E.S.C. station, Lester (1974) has calculated the rate of mean monthly rainfall to mean total precipitation and suggests that snow accounts for as much as 60% of the total. Powell (1973) on the other hand, states that a value of 40% for snow at E.S.C. is normal. A few kilometres south of E.S.C. at Marmot Creek, Storr (1967) estimates that 70 to 75% of total precipitation is received in the form of snow, and in the higher divide areas it is more than this. Thus the potential variations in amount and form of precipitation are obvious, even over short distances. A more detailed description of the precipitation characteristics in the Kananaskis District will appear later in this section.

The influence of terrain characteristics other than elevation such as slope and aspect, and vegetative cover, singularly and in combination have also been investigated. Golding (1970) working in Marmot Creek, attempted to explain the variation in snowfall amounts in terms of physical variables including elevation, slope, aspect and vegetative characteristics, but achieved only marginal success. Several investigators in the United States have examined the effects of elevation and slope on precipitation especially snow accumulation (Packer, 1960, 1962, 1971; Anderson, 1963). Packer (1960) tested

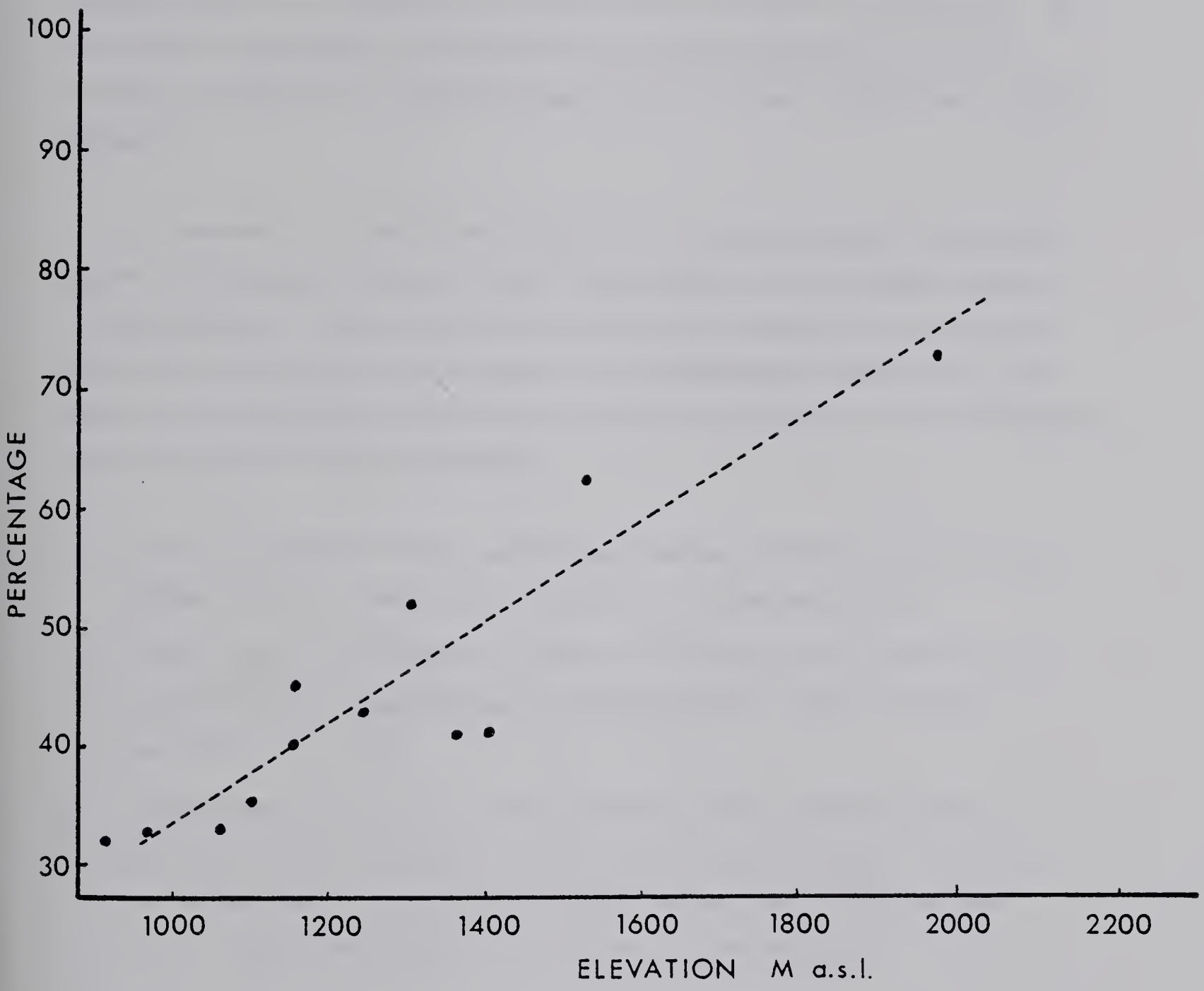


Figure 3.2i Average annual snowfall as a percentage of average annual precipitation, Banff and Jasper National Park snow courses.

Source: Janz and Storr, 1977

snowfall years, elevation, slope,aspect, canopy density and their interactions as variables in a curvilinear multiple regression. He found that the product of snowfall years and elevation, and the product of aspect and elevation were the only two significant interactions.

In summary, a precipitation-elevation relationship does exist, however the exact nature of this relationship has not been conclusively proven. Most studies have depicted a linear situation with measured precipitation increasing with increasing elevation. However, it is suspected that above a certain elevation this relationship is not valid for three reasons:

1) after saturation levels have been reached within the air mass, further uplift results in a decline in precipitation,

2) steep slopes and ridges at sharp angles are not conducive to receiving large quantities of precipitation while cirques and bowls are, and

3) high winds would tend to redistribute most precipitation, especially snow, away from the exposed upper slopes. Since few measurements are available for areas above 2500 metres a.s.l. (8200 feet a.s.l.) the above is conjecture.

The relationship between elevation and precipitation form is also of interest and available data suggest a rough approximation of a linear association. However other factors such as slope, aspect, season and storm characteristics are believed to be as influential in different situations. The significance of snow, especially its spatial and temporal variations, is of importance to both land and watershed management practices. For this reason, special emphasis will be placed on the characteristics of snow in the Kananaskis District in section 3.3 which deals with detailed climatic patterns.

3.2.4 Evapotranspiration

There is little information on the effects of topography in mountainous regions on evapotranspiration. Direct methods of measurement using class A pans (evaporation) and heat pulse methods (transpiration) are not widely employed. Most research has been on evaporation, using indirect methods such as energy-budget calculations (Bergen and Swanson, 1964; Storr, 1968, 1974, 1977; Louie, 1977; Golding, 1978). Estimated amounts of evaporation from snowpacks ranged from 1.8 mm (.07 in.) per day (Bergen and Swanson, 1964) in the Colorado Rockies, to as much as 13 mm (.5 in.) per day (Storr, 1968) under Chinook conditions in Marmot Creek. Information on evaporation from class A pans has been collected from the main weather station at Con 5 in the Confluence sub-basin in Marmot Creek since 1963. From 1971 to 1973 inclusive, additional pans were set up and maintained at two other sites, Con 5 in the Confluence sub-basin and at Cabin 5 in the Cabin Creek sub-basin in Marmot Creek. Table 3.2c lists the unadjusted mean monthly totals for the three stations. Con 1 experienced on average higher mean monthly totals of evaporation than Con 5 and markedly higher amounts than Cabin 5. In fact the average monthly difference in totals between Con 1 and Cabin 5 was 37.6 mm (1.48 in.) in July and 29.9 mm (1.18 in.) in August. While there appears to be a decrease in total evaporation with elevation, the period of record is not sufficient to allow for a detailed statistical analysis. Con 1 and Con 5 share similar aspect characteristics (east), while Cabin 5 is more exposed with a southeast orientation. The orientation factor may be ultimately responsible for the small total difference between Cabin 5 and Con 5 even though the difference in elevation is larger than between Con 5 and Con 1. There are no recorded attempts at establishing a quantitative relationship between evapotranspiration and physiographic variables, but a number of trends are apparent from different sources.

TABLE 3.2c

Unadjusted Mean Monthly Totals of Evaporation for Stations in Marmot Creek

STATION	ELEVATION	JUNE	JULY	AUGUST	RECORD
CON 1	1617 M	116mm	145mm	140mm	1971-1973
CON 5	1754 M	91mm	119mm	110mm	1963-1976
CABIN 5	2090 M	---	107mm	110mm	1971-1973

1 inch = 25.4mm

Source: Hydrometeorological Data for Marmot Creek, 1963 - 1976. Environment Canada

In order for evapotranspiration to occur, two factors are necessary, a supply of energy to drive the process, and an atmosphere sufficiently dry to accommodate the evaporated moisture (ie. a vapour pressure gradient). Two other factors, low atmospheric pressure, and wind, are important in deciding the rate at which the process will occur. Establishing the exact nature of the energy supply is a complex process in itself and often requires data which are not normally available, especially in mountainous areas. Storr (1974, 1977) used the energy budget approach in his study of evapotranspiration of Marmot Creek basin as a whole, and for each of the sub-basins. In brief this involved: (a) adjusting the measured net radiation for the average slope, aspect, and vegetative cover of each sub-basin to obtain averages of the available energy each month, (b) budgeting appropriate amounts for photosynthesis, the energy loss into or out of the ground and forest, and that used to melt the snowpack, and (c) separating the remaining fluxes of latent and sensible heat by the use of the Bowen Ratio (Storr, 1977). For the entire basin, streamflow has shown to be approximately one half precipitation, however, the ratio of streamflow to precipitation varied from one sub-basin to the next. For example, Cabin Creek sub-basin, with its higher percentage of south facing slopes experienced higher evapotranspiration (ie. streamflow/precipitation ratio of 0.433) than Twin Creek sub-basin with its large percentage of north facing slopes and a ratio of 0.585 (Storr, 1977). The effect of aspect and topographic shading then, are important factors to be considered in watershed management, especially if the objective involves manipulating the element of evapotranspiration for water yield or regime purposes. Golding (1978) investigated the effect which individual Chinook events had on snowpack evaporation. He found that the spatial variation in evaporation was due mainly to differences in windspeed. At a given elevation, snowpack evaporation was not greater at major

mountain gaps than along mountain ridges where no gaps existed, however, it was greater above treeline, again due to higher wind speeds (Golding, 1978).

Even though quantitative data on physical-evapotranspiration relationships are not available, there are good reasons for such relationships and they could be used to establish seasonal patterns. Transpiration from vegetation only occurs in the summer months and given that sufficiently large portions of the Rocky Mountains are above the treeline, these areas would contribute variable amounts of transpired moisture due to the presence of alpine meadows which would have nearly as much as downslope treed areas, to bare rock areas which have small evaporative losses and minimal transpiration losses from scattered vegetation. In other words, though both a temperature gradient and a vapour pressure gradient may exist at upper elevations, the variable lack of moisture storage present limits the amount and occurence of the process. On a seasonal basis, the above assumptions are valid, however on an annual basis, they are not so clearly defined. Since winter snows stay on the higher ridges for a longer period of time they are susceptible to evaporative action, especially during warm periods, such as Chinooks, and during the late spring and early summer months when the amount of incoming radiation increases dramatically. That the amounts of evaporation will be influenced by both elevation and aspect is deduced from experimental findings (Storr, 1977; Golding, 1978).

In summary then, a seasonal relationship between evapotranspiration and physical-elevational controls may exist. In summer, the amount of evapotranspiration will decrease with elevation proportional to other variables such as aspect, slope and vegetative cover characteristics. In winter when transpiration is negligible, temperatures are sufficiently low to effectively reduce the amount

of evaporation from snowpacks. Only during infusions of warmed air such as during a Chinook, would there be any significant losses of moisture. Storr (1968) summarized the information best by stating "....it is unlikely that a significant amount of.... evaporation takes place from radiation during mid-winter months, but some is likely in April and May". It is believed that a complex relationship exists between evaporation and topographic and meteorological characteristics, which can be deduced qualitatively at this time.

3.3 KANANASKIS PRECIPITATION CHARACTERISTICS

The previous discussion on precipitation dealt with the broad scale factors which influenced distribution patterns, and examined the relationship in which topography, especially elevation, influences both form and amount. Problems in establishing precipitation patterns for areas where data are scarce have been commented upon by Laycock (1978), Powell (1977), and Janz and Storr (1977), yet the use for such information in both hydrological and land use studies is becoming more imperative. For example, the frequency and distribution of measurable precipitation, can have an impact on streamflow responses within a basin and subsequently influence the siting and operation of water control structures. Similarly, this information can be of use to land use managers in planning the location of major recreational faciliteis such as campsites or ski resorts and to foresters and others to better their understanding of the effects of harvesting operations on flooding, erosion, sedimentation, and water quality.

The intensity with which precipitation occurs can also be of significance for similar reasons. For example, a 25 mm rain (1.0 in.) which falls in fifteen minutes can cause a much higher peak flow on streams and therefore require large culverts, higher bridges and more stable road cuts, than the same amount

spread over 24 hours (Janz and Storr, 1977). Large snowfalls in winter can cause problems for transportation and communication facilities, and adversely effect wildlife and their habitat.

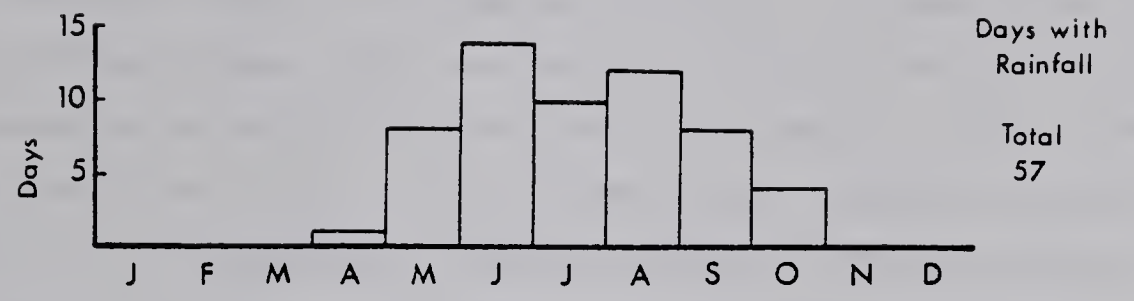
The last problem mentioned above is of particular concern, since precipitation in the form of snow may be of greater significance for watershed and land use planning in the Eastern Slopes. Of particular interest here are the variations in annual and seasonal snowfall amounts within the District and their influence on the hydrology of the basin. A study of snowcover characteristics, especially the spatial distribution, depth and water equivalent, will supplement the limited data on snowfall amounts to provide a better appreciation of the significance of snow.

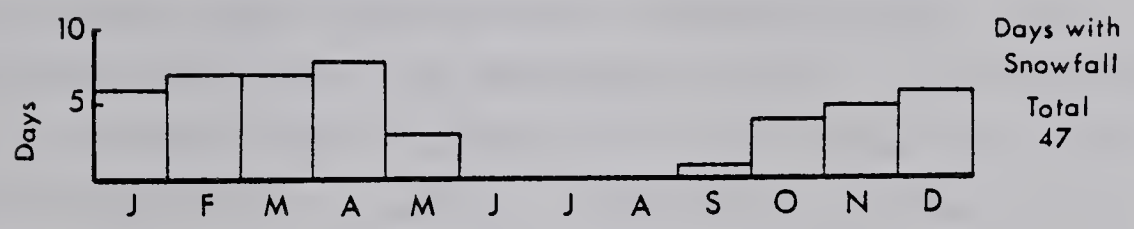
The ultimate objective is to combine this information, with other literature sources, and develop a map of precipitation patterns for the whole Kananaskis District. The compilation of such a map will require recognition of physiographic adjustments and employ a variety of measurement and analysis for a variety of purposes, especially in watershed and land use planning. The following is a detailed discussion of the various precipitation characteristics mentioned above.

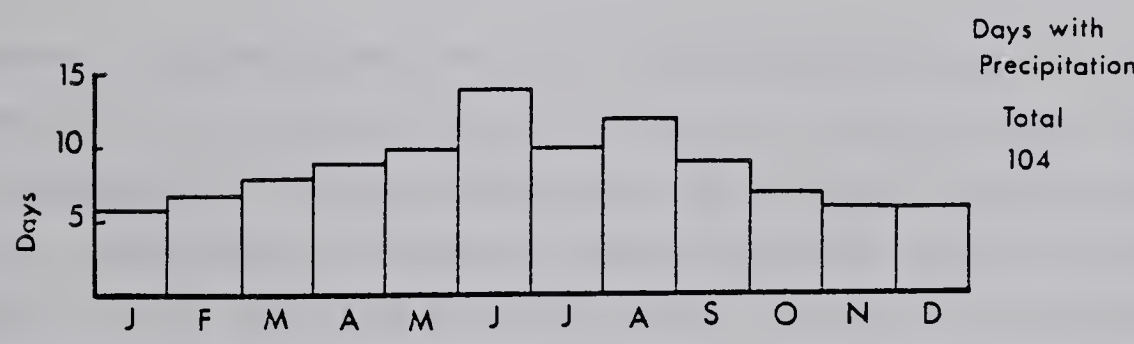
3.3.1 Frequency

Given the existing data bases, it is difficult to compare records of precipitation frequency between stations in the Kananaskis District. Only one station, E.S.C., has a record sufficiently long enough (over 30 years) to provide information on an annual basis. The other stations in the valley all have intermittent records with the majority of the data collected for the summer period only. Figure 3.3a depicts the frequency of measurable precipitation, including rain and snow, and the total and average monthly precipitation for Kananaskis E.S.C. There appears to exist a well defined relationship between mean monthly precipitation and the corresponding monthly frequency. The June maximums of both frequency and amount are due to the shift of major storm tracks of extratropical cyclones from the Gulf of Alaska, to this part of the Eastern Slopes.

While long term averages tend to provide a reasonable expectation of results, short term and year to year records show some rather striking variations. For example, on many occasions the number of days of measurable precipitation exceeds the average, however, the total precipitation received is far less than the mean. Alternatively the opposite is true to other years, suggesting that precipitation intensity or duration may be the more significant characteristics. Comparisons between stations are difficult due to varying lengths of record, however, some trends are apparent. There does not appear to be a defined elevational relationship, as might be expected, since E.S.C. often experiences a higher precipitation frequency than do other stations in the district, all higher in elevation than E.S.C.. This is probably due to the presence of small, localized storms which move into the valley entrance from the Bow Valley under easterly upslope flow conditions, but do not penetrate further south. Similarities in both amount and frequency occur often due to the presence of massive weather







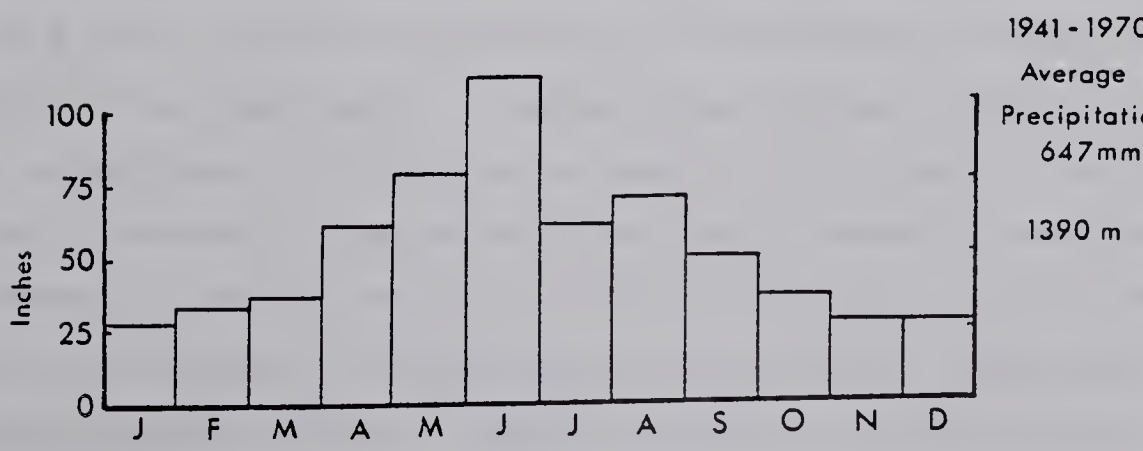


Figure 3.3a Precipitation Frequency and Amount, Kananaskis ESC.

Data: Environment Canada, 1976.

systems which influence a much greater region, especially during the winter months.

On a seasonal basis, the highest frequency is associated with the summer months (June, July and August), although August is the month of greatest precipitation variability (Powell, 1973). Few data on winter conditions exist. It is known that a snowfall maximum for both E.S.C. and Kananaskis Boundary Ranger Station occurs in April, however frequency data from the latter station are too intermittent to allow for a detailed analysis. Unfortunately no data are available for most upper alpine areas, especially those along the Continental Divide near the Kananaskis Lakes. It is suspected that more of the west coast regime could occur along the Divide, as records at Lake Louise suggest. The forestry lookout station east of the lakes is operated during the summer only and cannot supplement the seasonal data base.

In summary, there appears to be a relationship between precipitation amount and frequency only if there is a sufficiently long period of measurement. Close examination of weather records suggests however that variations in frequency from one month to the next and from one year to the next may be sufficiently large to preclude any confidence in a quantitative relationship. A seasonal maximum is apparent at E.S.C., but the extension of this record to other areas of the District is inadvisable. Comparisons between stations do not reveal significant differences or similarities based on elevation. Location and storm-scale characteristics would probably have the greatest amount of effect on precipitation frequency. Variations in precipitation intensity and duration are probably responsible when stations exhibit similar frequency values, but experience vastly different total precipitation values.

3.3.2 Intensity and Duration

Information on rainfall, snowfall and total precipitation intensity in the Kananaskis District is scarce, however some preliminary analyses have been attempted, Marmot Creek and Kananaskis E.S.C. were, until recently, the only meteorological stations in the Eastern Slopes to have recording rain gauges. Traditionally rainfall intensity analyses contain evaluations of the maximum 5, 10, 30, and 60 minute and 24 hour rainfalls in terms of a specified yearly return period. In an early study, Storr (1963) published values which suggested a return period of 25 years for a 50 mm (1.9 inch) rainfall in 24 hours. Later, Storr (1967) revised and updated his analysis, providing values for 24, 48 and 72 hours in terms of 5, 10 and 25 year periods. These values are presented in Table 3.3a.

Lester (1974) examined the intensity of extreme rainfall occurences for KananasksisE.S.C., Marmot Creek (Con 5) and Kananaskis Lookout. Only the Marmot Creek station has data for periods less than 24 hours. The results shown in Table 3.3b include the information for the published period of record.

Janz and Storr (1977) investigated the relationship between rainfall intensity and elevation using data from Con 5 (1754 metres a.s.l. (5750 ft. a.s.l.)), Cabin 5 (2090 metres a.s.l. (6800 ft. a.s.l.)) and Twin 1 (2288 metres a.s.l.(7500 ft. a.s.l.)) in Marmot Creek and Calgary (1066 metres a.s.l. (2498 ft. a.s.l.)). Figure 3.3b depicts the results with reference to a 10 year return period. The diagram shows a rapid decrease of intensity with elevation for short period rainfalls, and approaches zero change for 12 hour falls with a slight increase in intensity for 24 hour falls. The authors' concluded that high intensity rainfalls were

TABLE 3.3a

Rainfall Intensity and Duration Values for Kananaskis E.S.C.

Rainfall Duration (hrs.)	Return Period (Years) 5	10	25
24	58.4	68.6	81.8
48	78.7	91.4	109.2
72	86.4	101.6	121.9

1 inch = 25.4 mm

All Values in mm

Source: Storr 1963, 1967

TABLE 3.3b

Extreme Rainfall Intensities for Kananaskis E.S.C. Marmot Creek (Con 5); and Kananaskis Lookout (K.L.O.)

STATION	RAINFALL PERIOD (HRS.)			PERIOD OF RECORD (YRS.)
	6	12	24	
Marmot (Con 5)	35.6	63.5	83.8	11
E.S.C.	-	-	81.8	31
K.L.O.	-	-	94.0	7

All Values in mm

1 Inch = 25.4 mm

Source: Canada, Dep't. of Environment, 1972; Lester, 1974

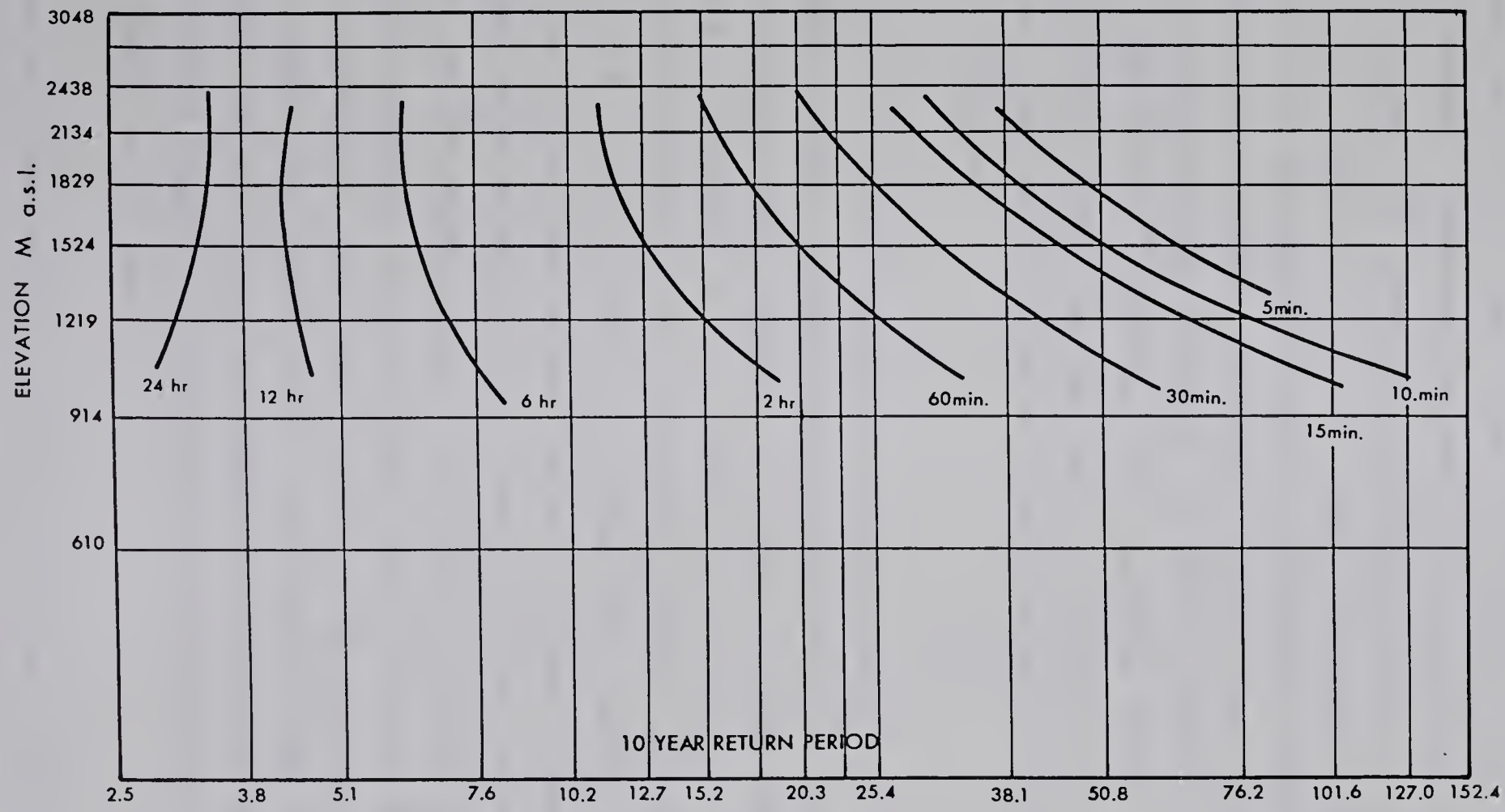


Figure 3.3b Rainfall Intensity vs. Elevation on East Slopes of the Rockies (preliminary results)

AFTER: Janz and Storr, 1977

more common and of longer duration at lower elevation. They attribute this to the Rockies and their influence on convective precipitation mechanisms (ie. the water content of convective clouds is less due to less space below the freezing level over mountainous terrain). However, the period of record is a short one of only 15 years, and there are insufficient data for above 2285 metres a.s.l. (7500 ft. a.s.l.). Also, the supposition that descending air over the Eastern Slopes is ultimately responsible for the variation in rainfall intensities, ignores the contribution which upslope winds from the southeast can make in certain years (MacHattie, 1968; Storr and Golding, 1976; Laycock, 1957b). The conclusions which are drawn for one area may be incorrect only a short distance away where air mass convergence and divergence patterns are different.

Measurement of snowfall intensity and duration is difficult due to problems in catch efficiencies of most precipitation gauges. Data for periods less than 24 hours are scarce, but the advent of snow pillows may alleviate this information gap if other problems concerning their operation (ie. condensation errors) are overcome. In their study of a severe April snow storm, Storr and Golding (1976) found that snow pillows gave values similar to those of nearby storage gauges, after corrections for temperature and pressure fluctuations, for the storm period. A frequency analysis of annual maximum 24-hour snowfalls at Con 5 showed that the storm of April 25-28, 1974, exceeded by more than 50 percent, the expected 100-year return period value (see Figure 3.3c). The best-fit line represents what would have been considered the expected values given the 11-year record, an extreme example of how inaccurate extrapolated values can be when record is too short.

It is not only mean maximum amounts of rain and snowfall which are important, but also the extreme maximum precipitation events which can significantly influence aspects of watershed management.

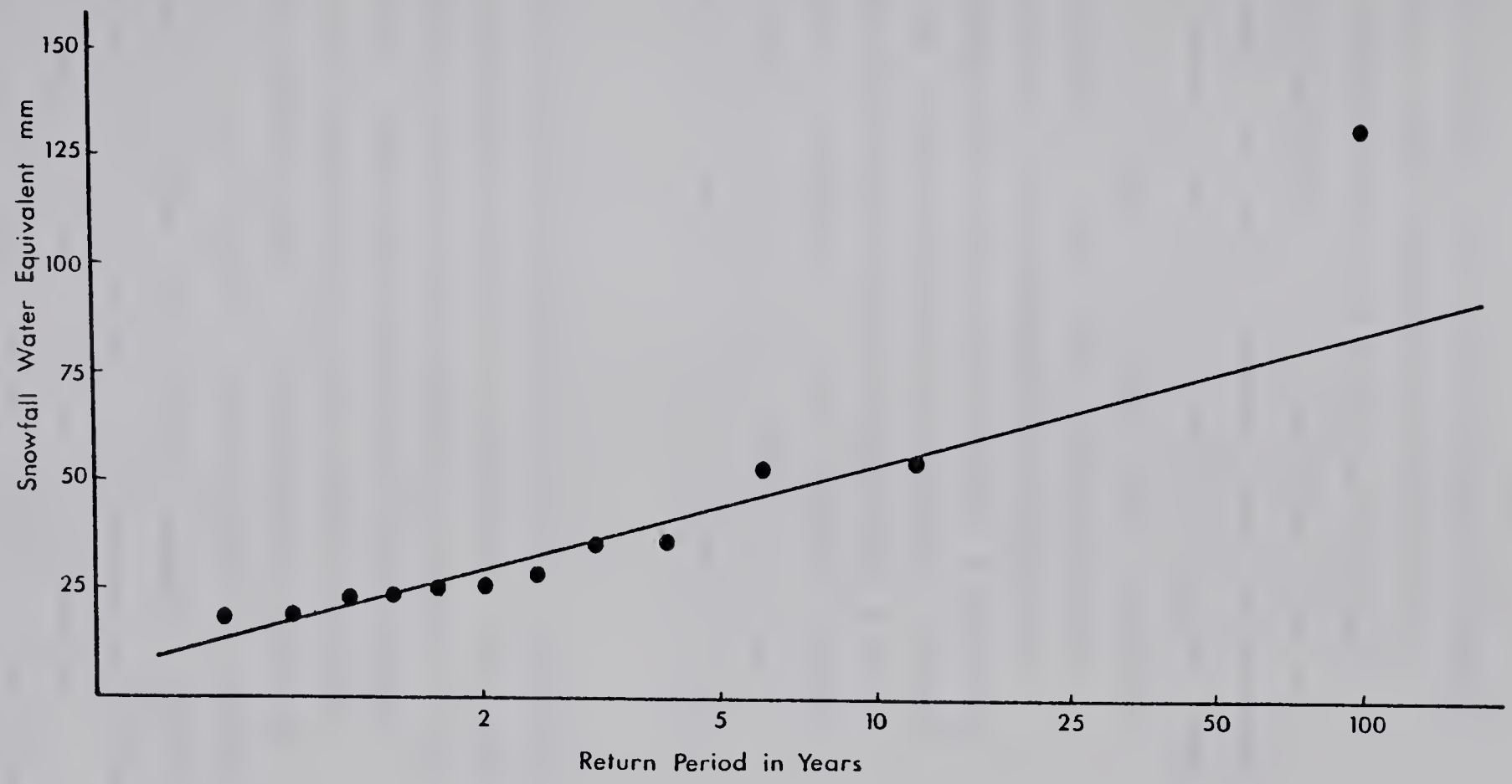
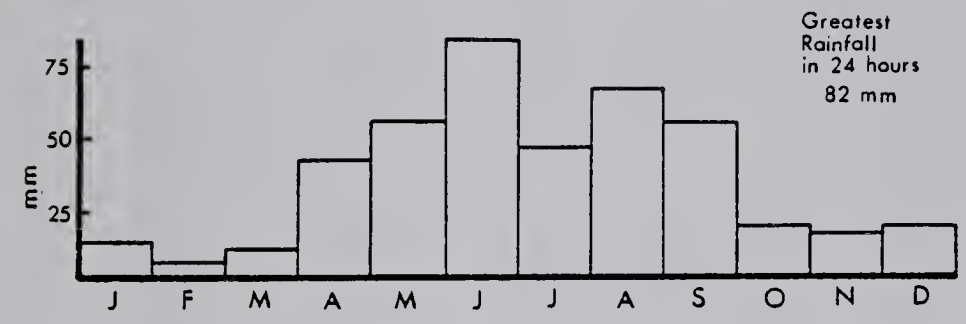


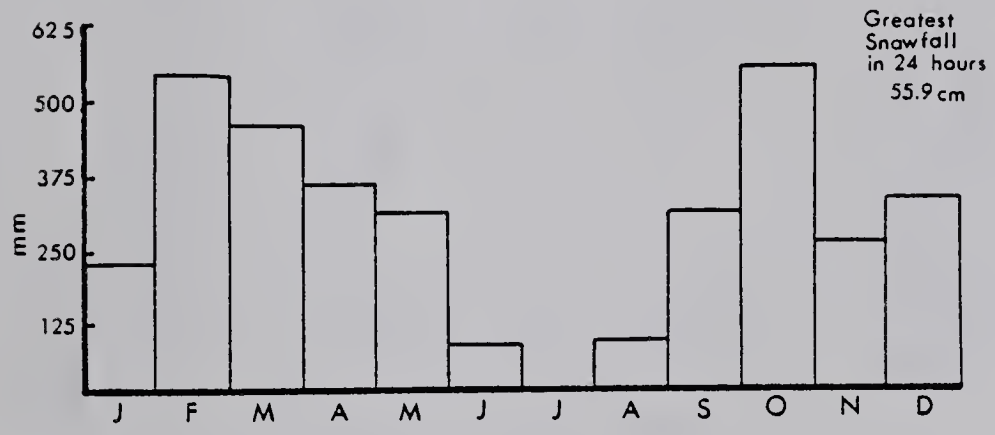
Figure 3.3c Frequency Analysis of Annual Maxima of 24 Hour Snowfall at Con 5, Marmot Creek.

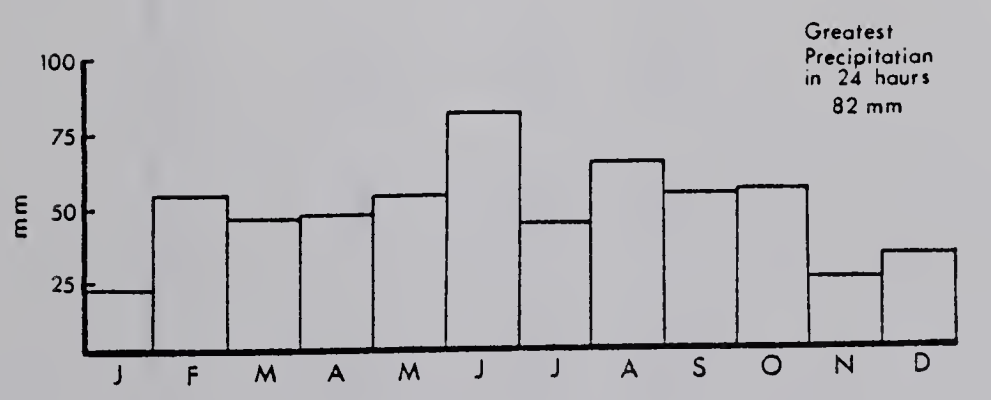
Extreme rain and snowfall events can cause flooding with heavy erosion and sedimentation, cause problems for wildlife and seriously hamper both communications (by hydro and telephone wires) and transportation movements. It is important then to consider the extreme events for design purposes, such as providing adequate storage and channel capacities to handle the runoff event, ensuring that facilities are designed to handle heavy rainfalls and snow loads, and planning to ensure that certain land use activities, such as logging follow recommended procedures to reduce erosion and sedimentation along skid trails. Figure 3.3d is an illustration of the 24 hour extremes in rainfall, snowfall and greatest precipitation for each month at Kananaskis E.S.C. Also provided for comparison purposes, are the computed normals for 1941-1970 of mean monthly precipitation. Table 3.3c is a listing of the extreme 24 hour snowfall for the period of record 1941-1970.

Information on precipitation intensity and duration variations in other parts of the Kananaskis District is unreliable since most stations are summer operated only and the length of record is too short. Results from E.S.C. show that precipitation intensities for individual storms of 24 hours duration may exceed the mean monthly averages in most winter months. This tendency is not so noticeable in summer due to the relatively high amounts of precipitation which are regularly received. Preliminary research suggests that the rate of decrease is less in storms of increasing elevation, but that the rate of decrease is less in storms of increasing longer duration. Initial studies which showed rainfall intensities of approximately 50 mm (1.9 inches) per 24 hours would have a return period of 25 years, have been revised to show that as much as 82mm (3.2 inches) per 24 hours is more reasonable for a 25 year return period (Storr, 1967). Similarly the 5 and 10 year return period rainfall intensities have been adjusted to 58 mm (2.3 inches) per 24 hours and 69 mm (2.7 inches) per 24 hours, repectively.

Figure 3.3d Precipitation Intensity and Duration Statistics - Kananaskis







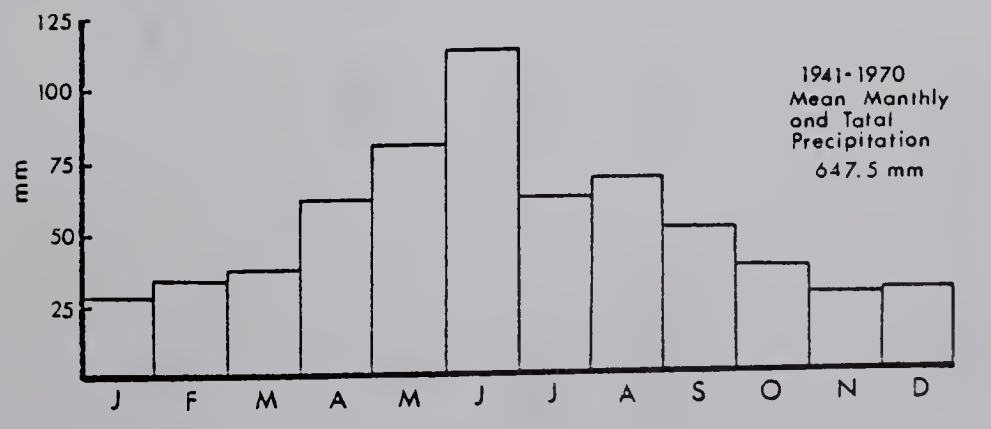


TABLE 3.3c

Mean Monthly and Extreme 24 - hour Snowfalls at Kananaskis E.S.C.

	JAN.	FEB.	MAR.	APR.	MAY	JUN.	JUL.	AUG.	SEPT.	OCT.	NOV.	DEC.	TOTAL/ MAX.
MEAN	27.9	35.1	37.1	54.1	20.1	7.9	0	4.8	8.9	25.9	26.9	29.0	266.7
EXTREME	22.1	55.1	46.0	36.1	31.0	7.9	0	8.9	31.0	56.1	24.9	33.0	56.1

All values in cm. Period of Record 1941-70

1 INCH = 2.54 cm.

Source: Canada, Dep't. of Environment, 1971, Lester, 1974

3.3.3 Snowfall and Snowcover

Though rain is the form of precipitation which many hydrological studies are concerned with, it is in fact snow which is probably the more significant of the two forms in the Kananaskis District. Estimates of snowfall as a percentage of total precipitation vary from place to place; however, 70% to 75% are common values (Storr, 1967; Laycock, 1957b, 1961). In the Kananaskis District, snowfall has been recorded at the Kananaskis E.S.C. since 1940 on a daily basis. In the 1950s several Sacramento storage gauges were installed by the Eastern Rockies Forest Conservation Board and were maintained by the Alberta Forest Service. In 1963 the Marmot Creek Experimental Watershed was established and that same year a Sacramento gauge was installed on the present Con 5 site. During the 1960s a number of gauges were discontinued in the vicinity of Pocaterra Creek, and east of the Kananaskis Lakes. Figure 3.3e depicts the past and present locations of measurement stations and Sacramento gauges. Published data for snowfall amounts is given both seasonally and annually, so comparison between stations can be difficult.

The mean annual total for Kananaskis E.S.C. is 265.7 cm (104.6 in.) based on the climatic normals from 1949 to 1970. Much of this snowfall is received in April, although other months may have higher amounts in individual years. Kananaskis E.S.C. is the only station in the District which can provide accurate annual snowfall data, since precipitation amounts are recorded on a daily basis. The use of recording gauges in Marmot Creek for snowfall measurement was attempted in the first few years of instrumentation (due to difficulties in accessibility) however, the results were unsatisfactory and storage gauges now furnish all the information on winter precipitation. The use of Sacramento gauges at Marmot Creek and at the other stations previously mentioned is necessitated due to inaccessibility during the winter months. These gauges are charged with ethylene glycol and covered with a thin film of oil to

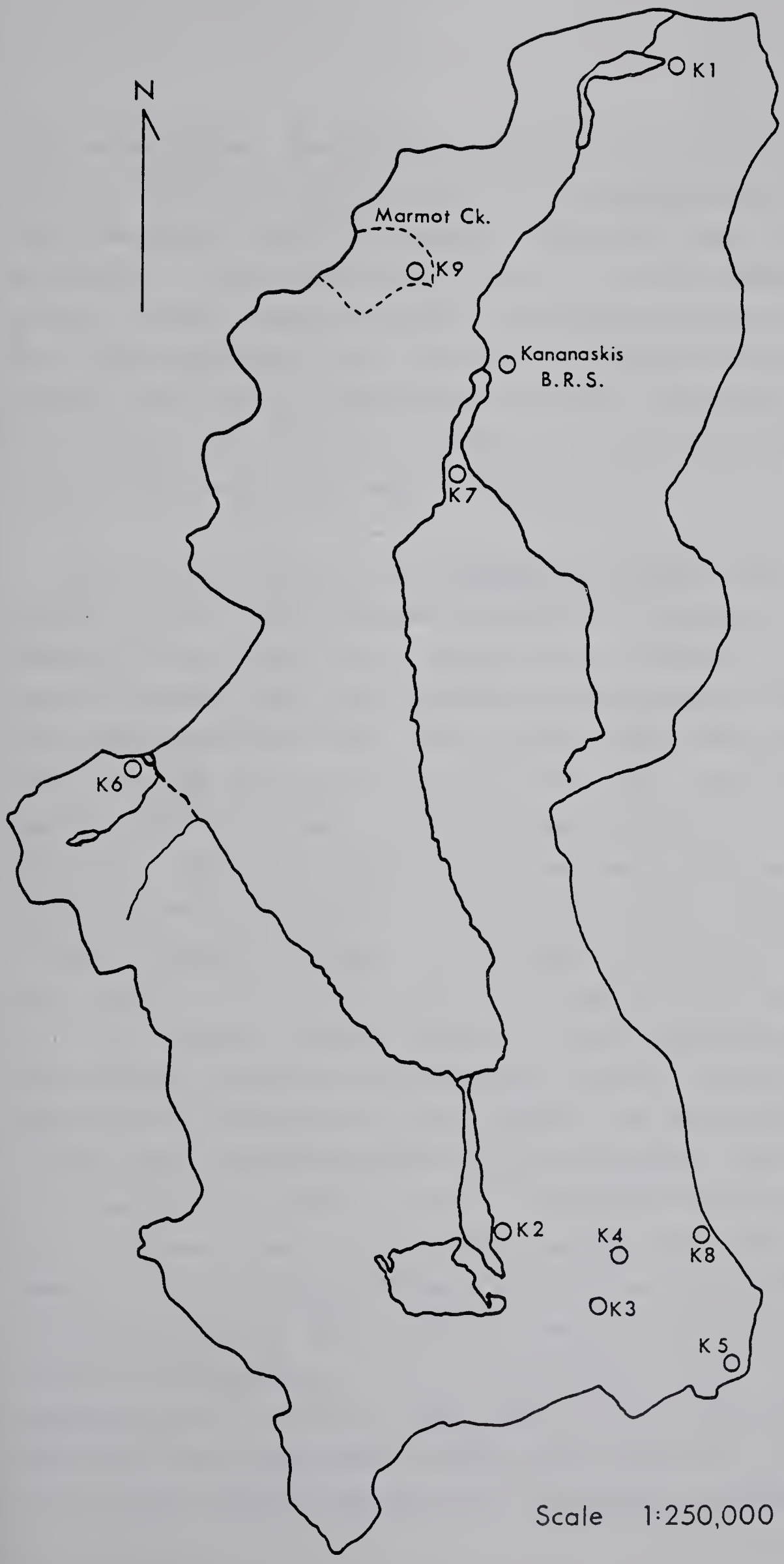


Figure 3.3.e

Snowfall Measurement Sites

Storage Gauges

K1 Kananaskis E.S.C.
various years

2 Kananaskis Lakes
1953 - P

3 Kananaskis Lookout
1954 - 64

4 Pocaterra Ck.
1954 - 64

5 Highwood Pass
1954 - P

6 Mud Lake
1954 - P

7 Evans-Thomas Ck.
1954 - 68

8 Elbow Pass
1954 - 68

9 South Marmot Ck.
1963 - P

limit evaporation. The gauges are read each fall (usually mid-October) and then remeasured again in the spring (usually mid-May) when access conditions improve. Obviously, some rain will be included in the spring reading, but it is also common for snowfall to occur before and after the readings have been taken. While this margin for error may not be acceptable to watershed managers, the storage gauges provide the best information on snowfall available in the Eastern Slopes and Mountain National Parks, and for this reason they cannot be ignored.

The storage gauges in the Kananaskis District that provide seasonal snowfall data (October to May) are of interest to those managing spring runoff, water storage, and streamflow. The Sacramento gauges in Marmot Creek were installed in the summer of 1963 and have been maintained since then. Fall reading dates have varied from as early as August 30th to as late as October 3rd. Similarly, spring readings have been taken as early as June 2nd and as late as August 2nd, therefore comparisons between years where dates of reading do not coincide must be made with caution. Winter precipitation, as measured between late September and early June varies from a low of 477.5 mm (18.8 in.) to a high of 1926.2 mm (40.4 in.). On average, rainfall dominates in both September and June, while May and October are months where snow and rain fall in equal proportions. Estimates of actual snowfall can be calculated using storage gauge and Fisher-Porter gauge information. For example, if the months of October to June are considered for the Twin subbasin in Marmot Creek for the 1972-73 season, the total seasonal snowfall is approximately 673 mm (26.5 in.) water equivalent. This corresponds to about 70% of the 967.7 mm (38.1 in.) received during the period of September 5, 1972 to September 6, 1973. Similar comparisons can be made for other years and for other gauge locations, with amounts and percentages varying with elevation. Estimates on an elevational basis, show that Con 5 receives, on average, about

355.6 cm (140 in.) of snow at 1754 metres a.s.l. (5750 ft. a.s.l.), Cabin 5 receives about 482.6 cm. (190 in.) at 2090 metres a.s.l. (6859 ft. a.s.l.), and Twin 1 receives about 597 cm (235 in.) at 2288 metres a.s.l. (7500 ft. a.s.l.). Storr and Golding (1976) employed Sacramento gauge readings, supplemented by information from snow courses and snow pillows, to map mean winter snowfall patterns for Marmot Creek (see Figure 3.3f).

Seasonal snowfall values are also available for the Kananaskis Lakes near Boulton Creek, Kananaskis Boundary Ranger Station, the Highwood Pass and Mud Lake. Kananaskis B.R.S. is located south of Marmot Creek at an elevation of 1463 metres a.s.l. (4800 ft. a.s.l.) and the snow gauge is located south of the station at an elevation of 1510 metres a.s.l. (4950 ft. a.s.l.). Average seasonal snowfall (Oct. 1st to May 31st) based on 24 years of record is approximately 269.2 cm (106 in.). The Kananaskis Lakes gauge near Boulton Creek is located at 1678 metres a.s.l. (5500 ft. a.s.l.) and has an average seasonal snowfall to 345.4 cm (136 in.) based on a 25 year period of record. Mud Lake gauge is located a short distance from the headwaters of Smith-Dorrien Creek at an elevation of 1906 metres a.s.l. (6250 ft. a.s.l.), and receives on average about 457.2 cm. (180 in.) of snow based on a 24 year period of record. The Highwood Pass gauge is located between the headwaters of Pocaterra Creek and the Highwood River. Located at an elevation of 2211 metres a.s.l. (7250 ft. a.s.l.), this gauge receives on average about 531.2 cm (248.5 in.) of snow based on a 25 year period of record.

There is little information above 2288 metres a.s.l. (7500 ft. a.s.l.) with which to make estimates of snowfall but some general comments can be made. Studies of heat and water balance with reference to glaciers (Ried and Charbonneau, 1978) prove that there must be great amounts because summer melting capacities are greatly

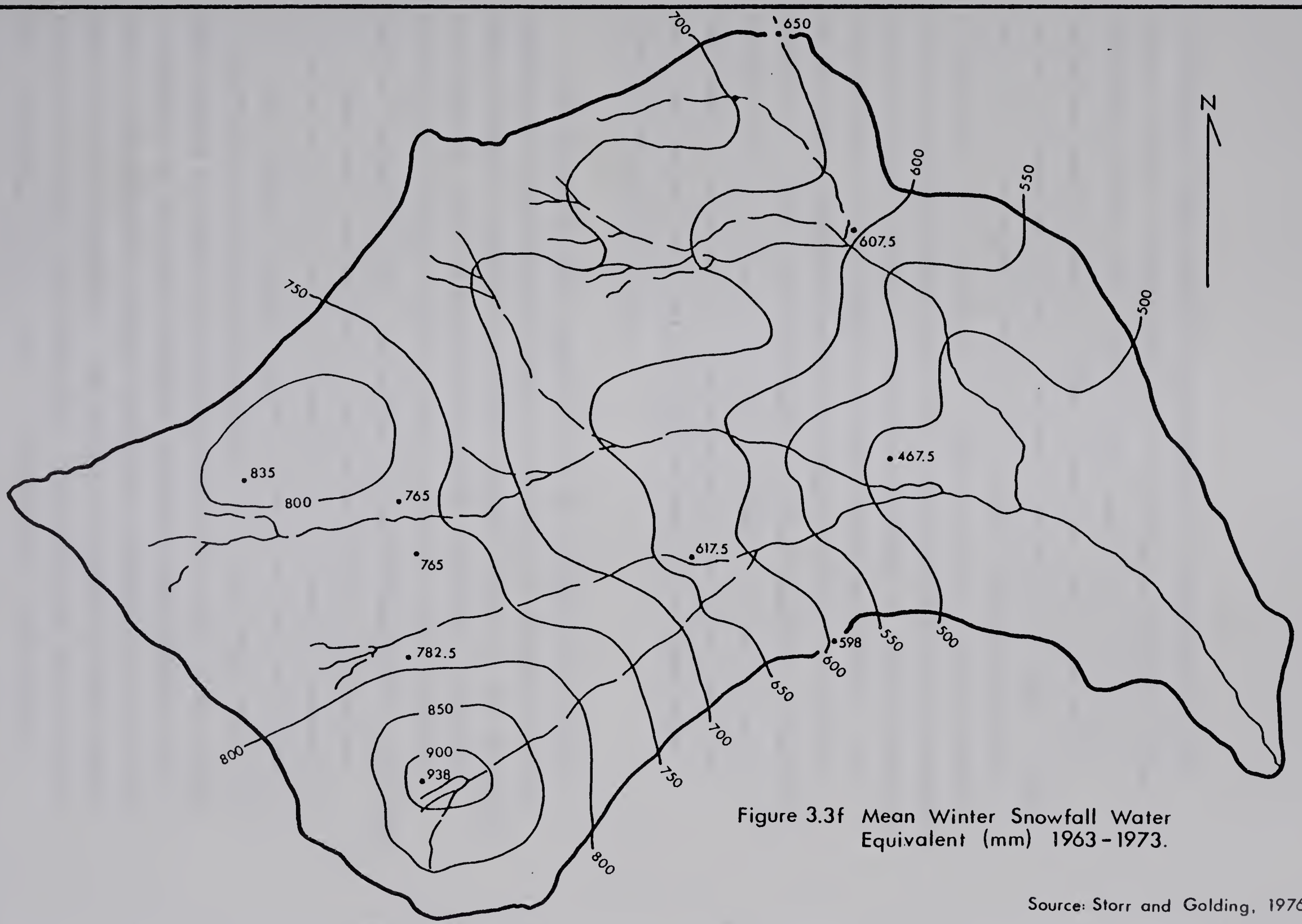


Figure 3.3f Mean Winter Snowfall Water Equivalent (mm) 1963 - 1973.

Source: Storr and Golding, 1976.

in excess of lesser supplies as evidenced by the Peyto and Ram glacier reports. Conversations with individuals working in the Kananaskis District also indicate that snowfalls occur in late spring and early summer at higher elevations, while the valley bottom is experiencing rain. Personal observations attest to this last point. On separate days in May of 1978 snow was observed falling above 1678 metres a.s.l. (5500 ft. a.s.l.) in the vicinity of the Kananaskis Lakes, yet a few km down valley the precipitation was in the form of rain. Estimates of snowfall at higher elevations are difficult to make based on meteorological measurements, yet we know from snowcover observations that snowfall must reach its maximum at a point just less than the highest elevation. Therefore, a detailed look at snowcover, its distribution on both a spatial and temporal scale, and its characteristics including depth and water equivalent, will help to fill in some of the gaps which snowfall measurement leave.

The snowcover which exists for up to 10 months in various localities in the Eastern Slopes is in reality a valuable form of water storage. Numerous direct and indirect users (on and off-site) are dependent upon the snowpack including vegetation, wildlife, hydro-electric power, municipal water supplies, and irrigation. Many of the major rivers, including the Saskatchewan River, are based in a large part upon snowmelt from regions within their basins. In order to provide better information for streamflow forecasting for a wide range of purposes, snow courses have been established to determine such parameters as depth, density and water equivalent. Measurements are taken by means of a Mount Rose snow tube, as near as possible to the date of maximum snowpack (approximately April 1) and at predetermined intervals during the snowmelt period until the snow pack has disappeared. The density of new snow varies considerably and depends upon temperature, wind and other factors, however the average density used in climatological reporting is

0.1. Therefore 10.0 cm (4.0 in.) of new snow would melt down to 1.0 cm (0.4 in.) of water. Spring snow course measurements characteristically show a much higher density of snow due in part to compaction and natural metamorphosis that the snowpack undergoes over the course of the winter. The water equivalent of the snowpack, perhaps the most important snowcover variable, is in part a measure of winter precipitation, but many factors change the amount and distribution of snow after it falls so the pack is not a true representation of the winter snowfall.

In the Kananaskis District snow course measurements are taken at Kananaskis E.S.C. (est. 1974), Marmot Creek (est. 1963 and successive years), Highwood Pass Summit (est. 1963) and Mud Lake (est. 1968). Information on snow depth and water equivalent is available from Water Survey of Canada publications and Alberta Environment monthly bulletins.

Snow depth and water equivalent are greatly affected by vegetation and terrain characteristics. For example, measurements for Marmot Creek in May 1974 show snow depth variations from 0 cm (0 in.) to 300 cm (118 in.) in an area of only 9.4 sq. km (3.6 sq. miles approx.). If we accept that precipitation increases with elevation, then one might expect a similar relationship between snow water equivalent and elevation. Golding (1974) found the following variations in snow water equivalent of the snowcover at the time of maximum pack. Snow water equivalent increased with elevation at rates of 1.25 cm. (0.5 in.) to 3.92 cm (1.5 in.) per 100 M (328 ft.). Snow water equivalent was found to decrease with an increase in slope by about 1 cm (0.4 in.) per 10 percent slope increase. Southwest and northeast aspects accumulated snow at one half to two thirds that of east and southeast aspects. Snow water equivalent was also found to decrease with increases in forest density, although no correlation was evident between the size of the decrease and the amount of the annual snow pack. In terms of

position in the basin, snow water equivalent increased from 9.4 cm (3.7 in.) on ridge tops to 12.5 cm (4.9 in.) on major slopes, to 20.9 cm. (8.2 in.) in local valley bottoms in Marmot Creek.

Since the date of maximum snow pack will vary from year to year measurements are taken on standard dates, either the first of the month or fortnightly. The analysis which follows uses information from both March 15th (approx. dates vary 13th to 18th) and April 15th (approx.) measurement dates. Figure 3.3g indicates snow course locations, while results are presented in Figure 3.3h and a number of general observations follow.

In view of the difficulty in establishing a 'representative' snow course, it is not surprising that a snow water equivalent-elevation relationship is not clearly evident. While the trend is toward greater snow water equivalent with elevation, there are anomalies due to differences in snowfall characteristics and snow course characteristics. Only Marmot Creek data are available for the March measurement period (usually March 14-18). At a glance it is obvious that MC21 and MC22 far exceed the average snow water equivalent values found at other stations of similar and even higher elvations. An explanation for these differences lies in their relative position. Both are located below major ridges and have a general north-northeast aspect. In this position they receive large amounts of snow that has drifted downwind from the windswept ridge tops. The northerly aspect results in less exposure to direct short wave radiation and thus less chance for evaporation. While higher precipitation is received at these upper elevation areas, much of it is redistributed by winds and avalanches, thus making direct comparisons between snow water equivalent and elevation difficult. Another factor which may affect the average values is the length of record of measurement. Both MC21 and MC22 have 5 year records while most other stations have from 10 to 12 years. However MC20 has only a 3 year period of record (based on 1977

Figure 3.3g

Snow Course Locations

Kananaskis District



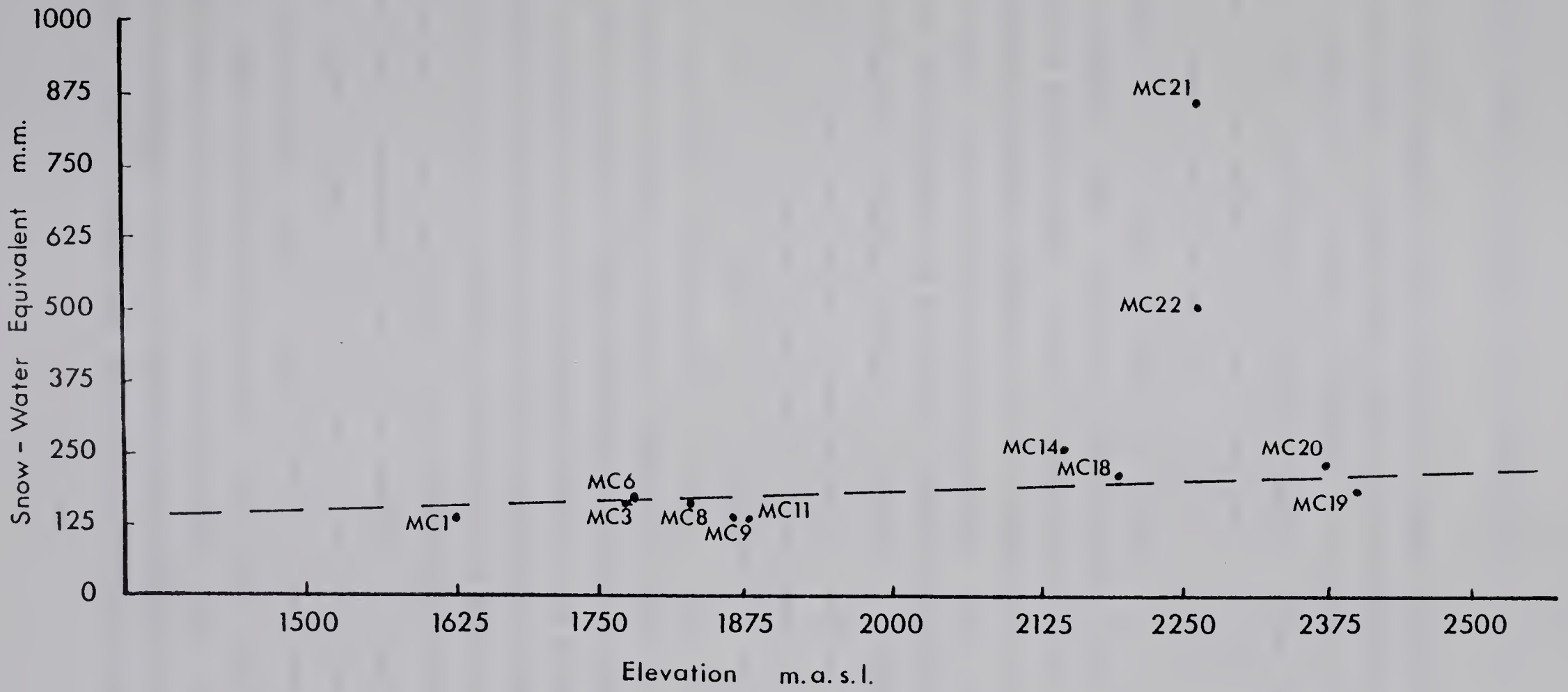


Figure 3.3h Average Snow W.E. vs Elevation for Marmot Creek Snowcourses in April, Kananaskis District.

Data Source: Snow Data, 1977.

published results) and its average is not anomalous.

The April 15th (approx.) data include the other stations in the District, and here a relationship even less pronounced is illustrated in Figure 3.3i. There is however a trend which is very apparent; that is the higher elevation stations experience large increases in snow water equivalent from March to April relative to the lower elevation stations. There are several possible explanations for these increases including; 1) that spring snow was heavier (more dense) and less subject to drifting after falling than winter snow, 2) that there was less wind activity preceding the April reading, 3) that some of the stations owe their increase to generally northeast exposures, and 4) that a snow-elevation relationship is related to seasonal energy balance regimes. Differences in average values for stations at similar elevations suggest that snow course characteristics such as aspect, exposure and proximity to major ridges may be more important. The anomalous nature of MC21 might best be explained by avalanching in combination with other variables such as aspect, orientation, elevation, slope and proximity to major ridges. The use of such a snow course as an index for depth measurements may be limited unless it can be shown that it is representative of the general area. The apparent difference in snow water equivalent between Mud Lake and other stations at similar elevations is due to its location. Situated on the lee slope of the Continental Divide it no doubt receives considerable spillover snowfall. That the Highwood Summit snow courses, also situated in the lee slope of the Continental Divide, do not receive proportionately more snow water equivalent for their elevation may be due to the extra intervening mountain range before the Divide. Moisture bearing winds from the west would lose large amounts of snow before reaching the Continental Divide as it passed over Mount Joffre and the Petain

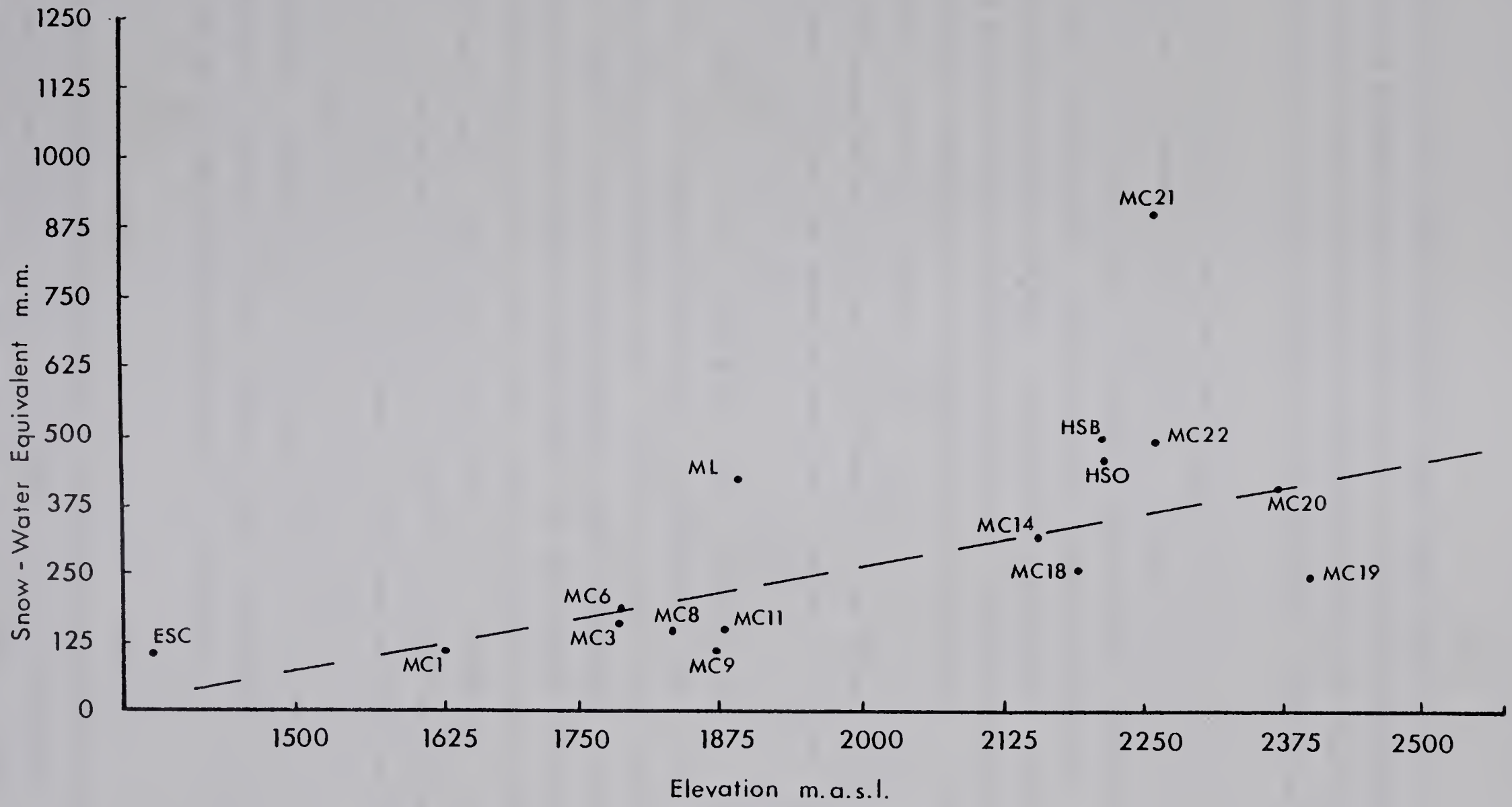


Figure 3.3i Average Snow W.E. for All Snowcourses in April, Kananaskis District.

Data Source: Snow Data, 1977.

Glacier in the Elk Lakes Provincial Park region, just west of the Divide and Highwood Pass. While this is a subjective assessment, it is valid since the presence of numerous glaciers in the ranges to the west is a strong indicator of differential snowfall amounts.

It is difficult from the foregoing discussion to make any definitive statements about snowcover. While it is clear that snow water equivalent increases with increasing elevation, other factors may be more significant, such as season, aspect, orientation, slope and proximity to major ridges. Snow courses are useful as an index to how much water may run off in the spring, although information on snowcover variations on a temporal basis with respect to first appearance and final disappearance is generally not available unless repeated seasonal monitoring is carried out. In Marmot Creek, where snow courses are measured until all the snow is gone, the trend is toward rapid depletion of the snowpack below 1830 metres a.s.l. (6000 ft. a.s.l.) during the first few weeks in May. By the end of May, the snowcover has usually disappeared, while that on slopes between 1830 metres a.s.l. (6000 ft. a.s.l.) and 2135 metres a.s.l. (7000 ft. a.s.l.) has undergone rapid depletion. It is significant to note that in some years, no snow exists in any of the snowcourses past the end of May, while in other years considerable amounts may remain above the 2135 metres a.s.l. (7000 ft. a.s.l.) level. For example, snow depths of over 254 cm (100 in.) were measured above 2135 M (7000 ft.) in mid-June of 1974 when snow below this level had disappeared as much as two weeks earlier. In fact, measurements continued into the second week of July, where snow depths in excess of 101.6 cm (40 in.) and snow water equivalent greater than 508 mm (20 in.) were found above 2257 metres a.s.l. (7400 ft. a.s.l.).

Snow pillows provide what might be the best record of snowcover water equivalent and its rate of depletion during the spring. Unfortunately, these have only been in use since 1973, and only in

Marmot Creek (see Figure 3.3j). Still they provide the best continuous quantitative and qualitative picture of snowcover available. Figures 3.3k and 3.31 depict the results from a high snowfall year (1974) and a year of relatively low snowfall (1977) for the period of record available. The 1974 results show the characteristic increases in snow water equivalent through the winter, culminating in spring maximum around May 25th for the Upper pillow, May 20th for the Middle pillow, and the Lower pillow showing two peaks, one in late April and the other on the 20th of May. The E.R.F.C.B. pillow, at the lowest elevation, shows both the characteristic peaks similar to the Lower pillow, but they are earlier and not anywhere near the same amount.

The 1977 results show snow water equivalent levels much lower (by almost five times) and a much earlier maximum of snow water equivalent around April 20th for both the Upper and Middle snow pillows. The lower pillow records a maximum near the 3rd of April with a total value of snow water equivalent much lower than the others. The fact that the Middle pillow recorded a higher snow water equivalent than the Upper pillow has not been explained and mechanical malfunctions have been ruled out (Hillman, pers. comm., 1979).

Storr and Golding (1976) have attempted to show the snow pillow's use as a snowfall measuring device on a single storm basis, but had difficulty with delayed responses relative to measured gauge amount. Storr (1979) used the U.S. Corps of Engineers Theoretical Snowmelt Model to calculate snowmelt on Marmot Creek, and found that snow pillow values compared very closely with those calculated by the model. The pillows, however, work best when the snowpack is stable, snowfall is absent, and the pillow is totally covered, during the period when calculations are made.

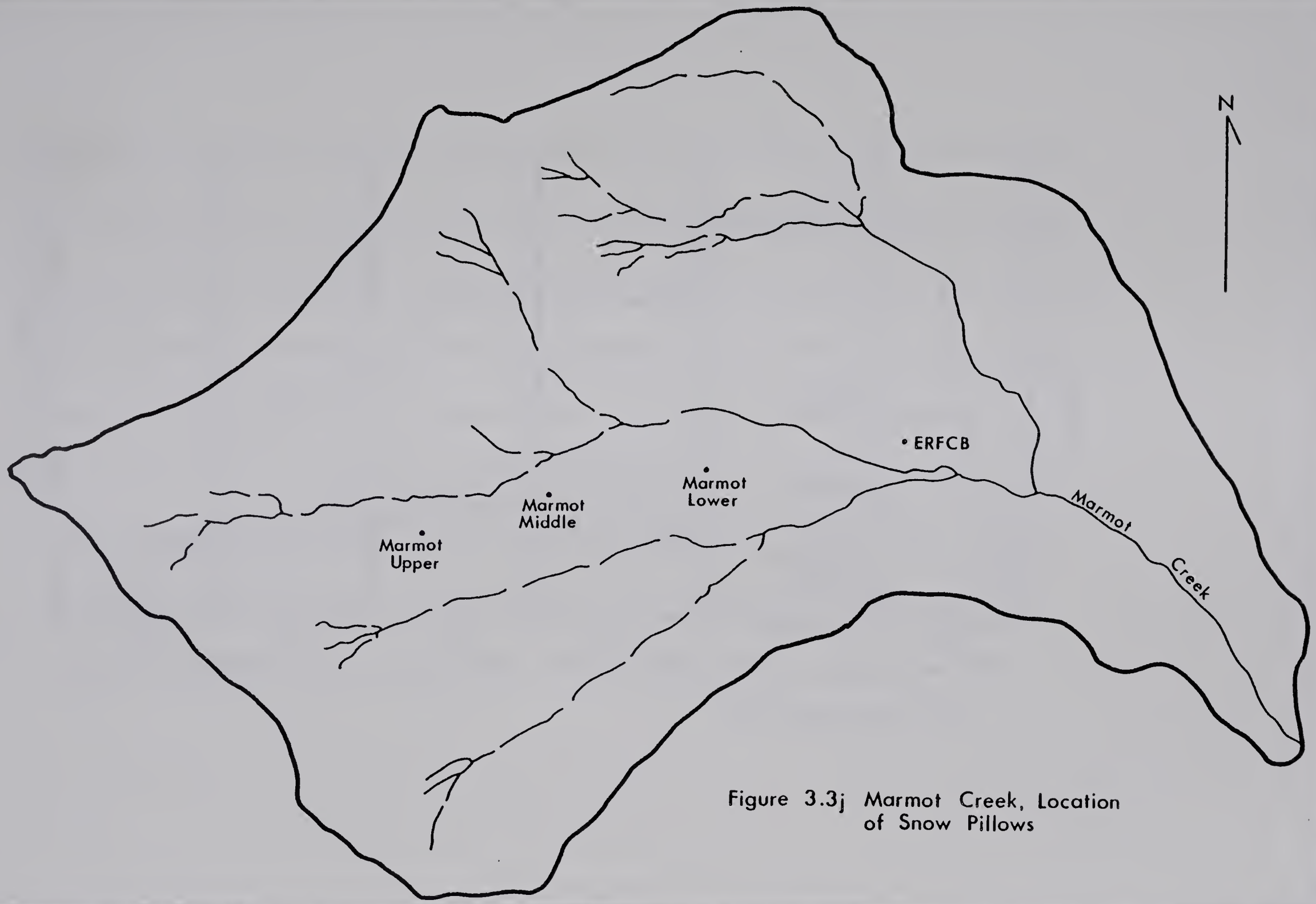


Figure 3.3j Marmot Creek, Location of Snow Pillows

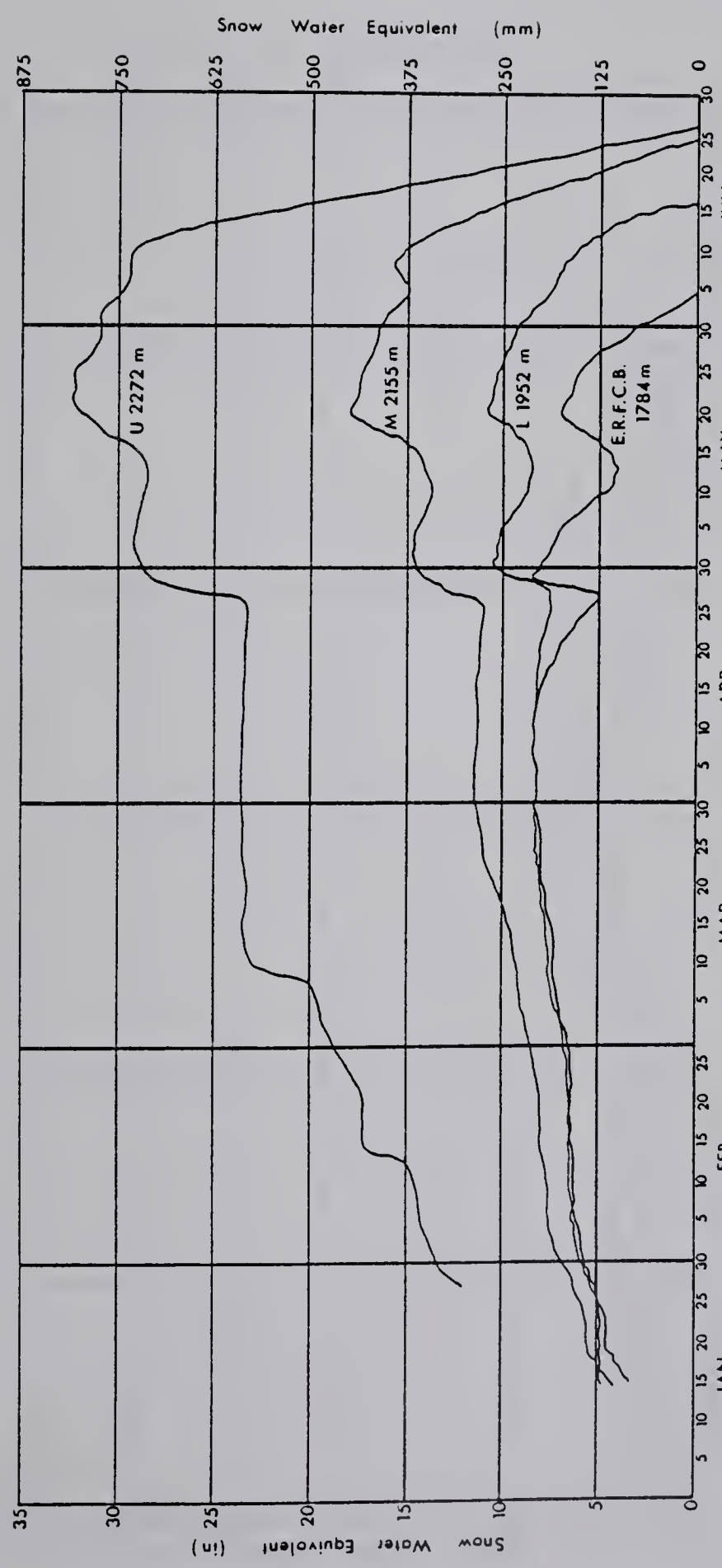


Figure 3.3k Snowpillow Traces for Upper, Middle, Lower and E.R.F.C.B. Pillows in Marmot Creek 1974

(Data: Environment Canada, 1977)

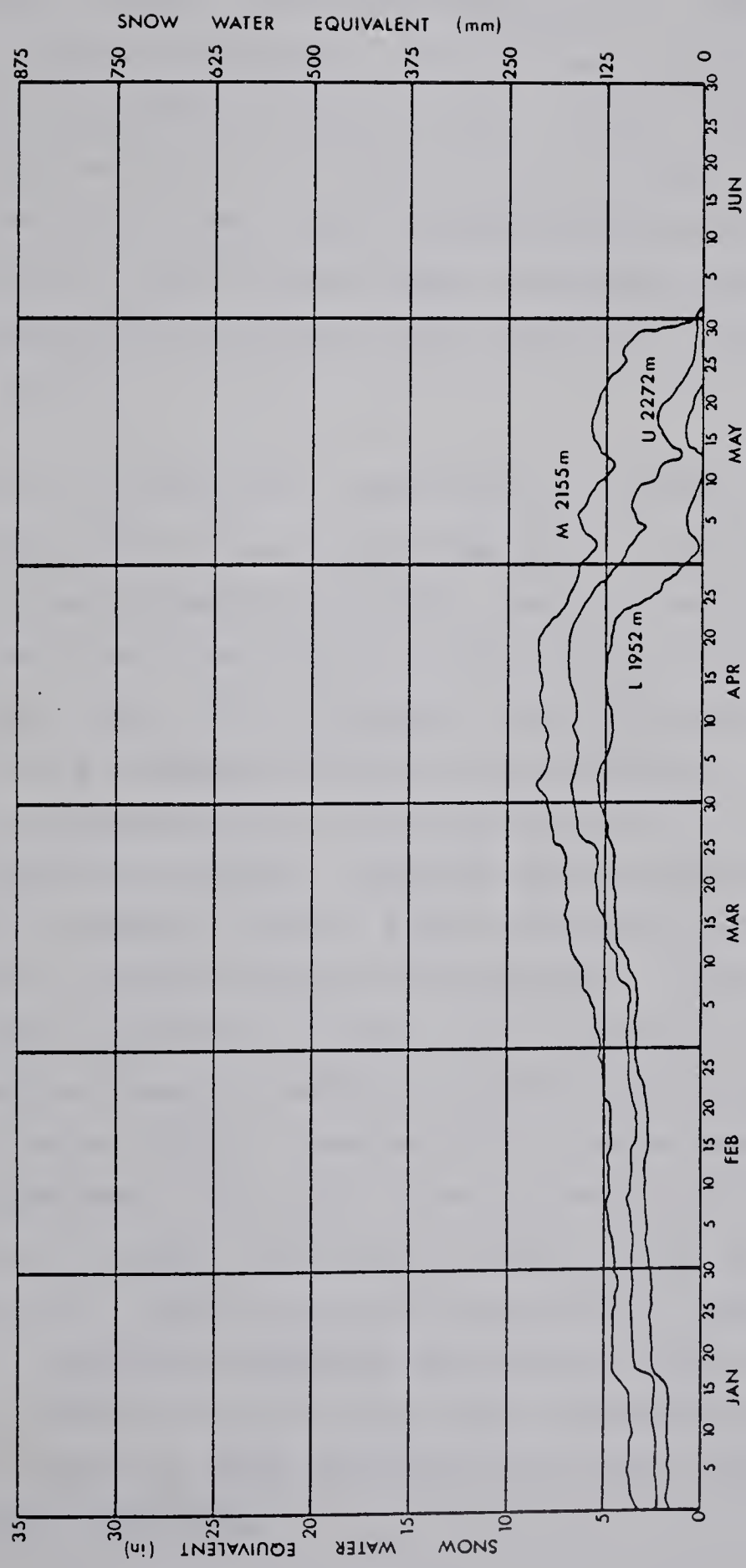


Figure 3.31 Snowpillow Traces for Upper, Middle and Lower Pillows in Marmot Creek 1977

(Data : Environment Canada, 1977)

Personal observations and remotely sensed satellite imagery confirm the temporal variations in snowcover described above. Most of the major valley bottoms, including the Kananaskis main valley and Evans-Thomas valley, below 1830 metres a.s.l. (6000 ft. a.s.l.) lose their snowcover during May, with the last remnants persisting in the upper Evans-Thomas until late May. South facing slopes above the 1830 metres a.s.l. (6000 ft. a.s.l.) also lose their snowcover. By the end of June, only scattered snow patches will be found in protected north facing slopes and dense brush hollows while permanent snowfields and glaciers are found above 2590 metres a.s.l. (8500 ft. a.s.l.).

There are at present few quantitative assessments of snowcover depletion rates, and no maps which show relative positions of seasonal snowlines for the Kananaskis District. Much of the discussion above is based on personal observations and discussions with long-time visitors to the area. Where possible, data from actual measurements combined with a knowledge of basic hydrometeorologic principles, has been used to substantiate the discussed results. In summary, the following trends are apparent. Snowpack water equivalent is higher and reaches its maximum later at higher elevations, supporting a site dependent snowfall-elevation relationship. Variations in snow depth and water equivalent are due to the interaction of a number of variables such as season, elevation, aspect, slope, exposure, and proximity to major ridges. Observations and measurements show that snowcover disappears from valley locations and most south facing slopes in May on average, while north facing slopes and areas above 2135 metres a.s.l. (7000 ft. a.s.l.) lose most of their snowcover by mid-June. Permanent snowfields and glaciers exist above 2592.5 metres a.s.l. (8500 ft. a.s.l.) and these contribute significant quantities of water to local streamflow long after the spring runoff period at lower elevations.

3.3.4 Average Annual Precipitation Patterns

In this attempt at mapping precipitation for the Kananaskis District, all available information has been used. This includes data from first and second order meteorological stations as well as those from part-year observations (ie. forestry lookout towers) and short-term unpublished research sources such as theses. As Laycock (1978) has suggested, additional information including snow course measurements have been used. The precipitation characteristics discussed in this Chapter have provided a basis for the preparation of the map. Conservations with individuals involved in hydrologic data collection and research, resulted in adjustments in certain areas.

A significant difference between this map and maps developed for other areas of the Eastern Slopes (Janz and Storr, 1977; Longley, 1972; Powell, 1977; Storr, 1969) is the use of hydrologic information, particularly that of streamflow. For example, calculated water yield data for available streamgauging stations with a period of record exceeding 10 years was used in water balance equations for estimating precipitation in upland areas. These procedures are widely used in various framework studies in the westen United States, one of the best being for the State of Idaho (see Idaho Water Resources Board, 1968). In this study, precipitation maps were prepared using adjusted climatological data values derived by correlation with physiographic factors, combined with runoff information from streamgauging stations. The streamflow information was used to fill in gaps where meteorological data was absent, and also as a check on values interpolated from actual precipitation records.

Laycock (1957b, 1978) utilized these same techniques in mapping precipitation for the Eastern Slopes and for all of Alberta. His maps recognize both the physiographic and runoff variations used to delimit the precipitation patterns.

In the analysis which derived the runoff and precipitation maps, the following procedures were used. Runoff values were generated from streamflow/basin area relationships for those gauges whose record of operation was at least 10 years in length. These values reflect the variations in topography, vegetation, soils and elevation within the area above each stream gauge. The mean annual, extreme minimum, and extreme maximum runoff values for each drainage unit above a gauge are presented in Table 3.3d.

The trend towards higher runoff in the higher, southernmost portions of the District is obvious, and is due to the unique climatic and physiographic characteristics of back range areas explained in previous sections. High runoff is characteristic of rocky alpine areas since soils and vegetation are thin or absent, thus resulting in low actual evaporation. Since retention storage is absent also, snowmelt and rainfall runoff is enhanced, reducing even further the actual evaporation which takes place. Colluvial and talus materials positioned downslope of the bare rock areas, are usually coarse and offer large detention storage capacities but high porosity reduces the retention storage capability of these deposits. Still, these areas would experience higher evaporation values than bare rock areas. Glacial, glacio-fluvial and alluvial materials while having lower porosity characteristics, offer higher retention storage in the lower slope and valley locations. These deposits are usually thick, although they may be thin in places, and as a result provide reliable supplies of water for vegetation. Thus evapotranspiration from soil moisture and vegetation increases in the lower valley locations, probably approaching precipitation in dry years.

These relationships, developed by Laycock (1957a) for the Eastern Rockies Forest Conservation Board, provide a qualitative picture of precipitation, evapotranspiration and runoff and the

TABLE 3.3d

Mean Annual, Extreme Minimum and Extreme Maximum Runoff Values for Selected Drainage Units, Kananaskis District

#1	#2	#3	#4	#5	#6	#7	#8	#9	#10	#11	#12	#13
Marmot Ck. (Main Stem)	05BF016	9.4	1.0	4,243	0.9	451.4	4,785	0.6	509.4	3083	0.9	327.9
Pocaterra Ck. (Near Mouth)	05BF004	55.7	5.9	27,754	5.7	498.3	37,000	4.6	664.3	19,736	6.0	354.3
Smith-Dorrien Ck. (Near Mouth)	05BF008	120.0	12.7	70,688	14.5	589.1	92,500	11.5	662.5	42,367	12.9	353.1
Kananaskis R. (Above Pocaterra Ck.)	05BF003	363.0	38.6	263,960	54.3	727.2	291,100	36.4	801.9	188,720	57.3	519.9
Kananaskis R. (Below Upper Dam)	05BF021	155.4	16.5	156,654	32.2	1008.1	173,920	21.8	1119.2	101,390	30.8	652.4
Kananaskis R. (Near Seebe)	05BF001	940.0	100.0	485,990	100.0	517.0	799,300	100.0	850.3	329,340	100.0	350.4

#1 - STATION NAME
#2 - STATION #
#3 - BASIN AREA (KM^2)
#4 - % TOTAL BASIN AREA
#5 - MEAN ANNUAL FLOW (DAM^3)
#6 - %MEAN TOTAL BASIN FLOW
#7 - DEPTH OF MEAN RUNOFF (MM)
#8 - EXTREME MAXIMUM FLOW (DAM^3)
#9 - % EXTREME MAXIMUM BASIN FLOW
#10 - DEPTH OF EXTREME MAX. RUNOFF (MM)
#11 - EXTREME MINIMUM FLOW (DAM^3)
#12 - % EXTREME MINIMUM BASIN FLOW
#13 - DEPTH OF EXTREME MIN. RUNOFF (MM)

(Period of Record is Variable)

1 DAM^3 = 1233.5 ACRE-FEET
25.4 mm = 1 inch

Source: Historical Streamflow Summary, 1979;
Water Survey of Canada,
Environment Canada

variation between these variables within a mountain watershed. Combined with streamflow information, these estimates of evapotranspiration based on elevation and physiographic and vegetative characteristics, can help produce reasonable areal values of precipitation.

The errors which earlier precipitation maps (Storr, 1969) contain are revealed by examining the runoff values on the previous table. Kananaskis E.S.C. receives 648 mm (25.5 in.) of precipitation on an annual average, while the streamflow gauge located near the station shows an average 518.2 mm (20.4 in.) of runoff. Since evapotranspiration measured at Calgary and estimated for Marmot Creek is 508 mm (20 in.) and 439.4 mm (17.3 in.) respectively, then E.S.C. can be expected to have evapotranspiration values in the 457.2 mm (18 in.) to 508 mm (20 in.) range on an average basis. Given the equation, that runoff equals precipitation minus evapotranspiration (change in groundwater storage is assumed to be negligible) it is obvious that precipitation in the upper slope and back ridge areas must be significantly higher than Storr's (1969) estimate.

The conservatism which pervades recent precipitation mapping (Powell, 1977) is also evident when compared to calculated water yield values. The streamflow gauge below Upper Kananaskis Lake reveals that, on average 1008.1 mm (39.7 in.) of runoff can be expected. Powell (1977) suggests that precipitation along the ridges paralleling the Divide would amount to 990 mm (35.4 in) annually, decreasing to 800 mm (31.5 in.) at lower elevations near the Kananaskis Lakes. Given that evapotranspiration values would vary markedly, from as high as 381 mm (15 in.) in the forested and exposed lower slope locations, to less than 127 mm (5 in.) in the bare rock and rocky alpine areas of the upper slopes, the precipitation values should be increased by almost as much again for

the high elevation ridges paralleling the Divide.

The precipitation map in Figure 3.3m was developed for this study using all conventional meteorological sources of information. The records from the Kananaskis Centre for Environmental Science, and various stations adjacent to the lakes, helped to confirm the values for valley bottom areas. Marmot Creek records were used to help derive the middle and upper alpine characteristics of precipitation and evaporation. A considerable amount of personal judgement has been used to construct isolines for the upper elevations, although they are supported by the soil, vegetative and water yield patterns discussed earlier. The precipitation values mapped for the lower valley bottom areas are in good agreement with existing maps (Powell, 1977; Storr, 1969). The isolines in the middle alpine area depend a great deal on Marmot Creek values and these are statistically reliable. Isolines plotted for upper elevation areas rely heavily on vegetation (where present) and soil patterns and relationships, and while these only provide estimates of water yield, the flow gauge values define the limits of yield from each sub-basin. The estimates of precipitation of upper elevation areas are averages, and water yield values do in fact suggest that they would be accurate to within ±10 percent in any given year.

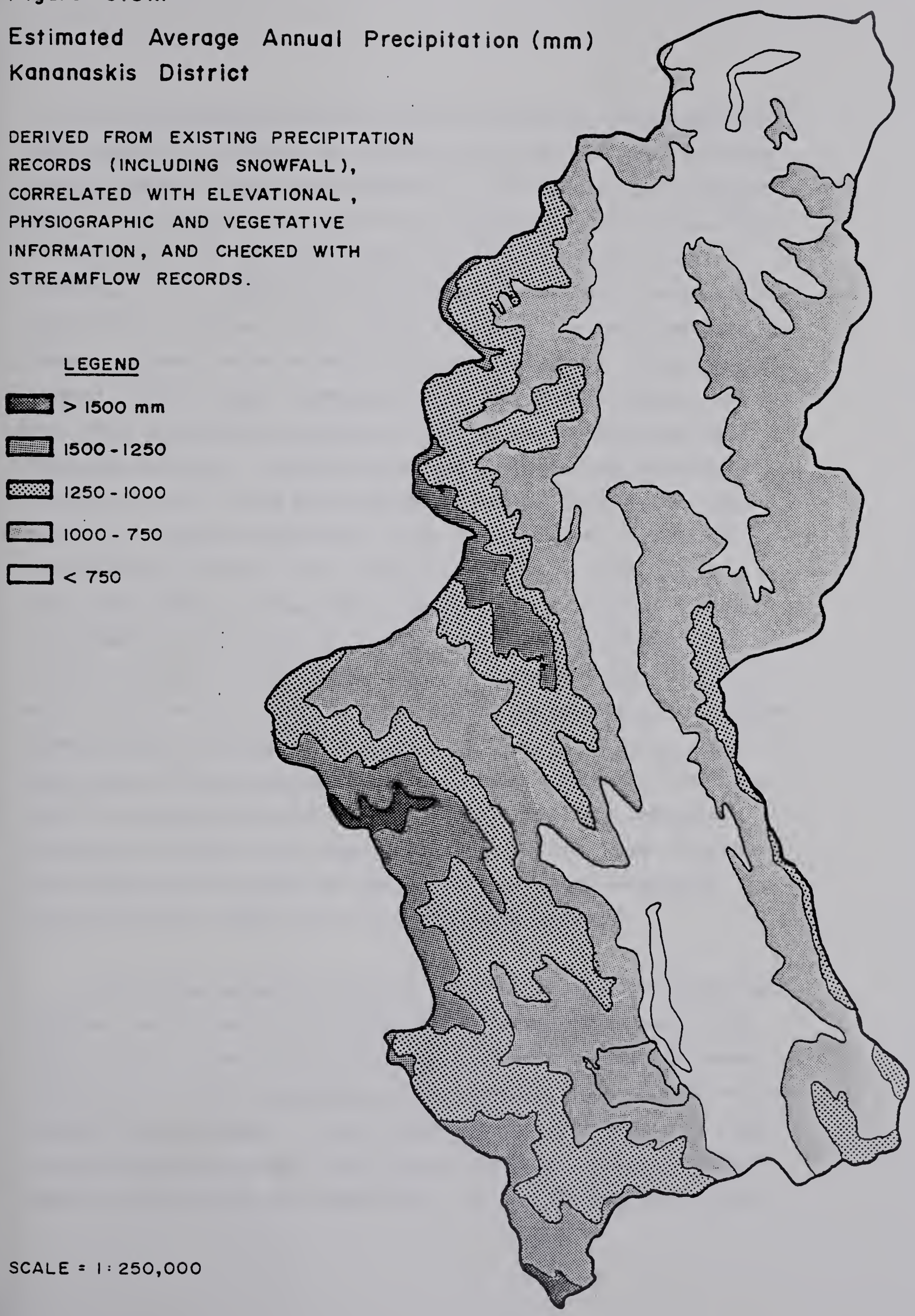
3.4 CLIMATE SUMMARY

Knowledge of precipitation patterns is a fundamental requirement of understanding the constraints which a watershed manager must operate under. Regardless of the management objective in a basin, the watershed manager would need to know areas of maximum precipitation, seasonal distribution, dominant form, existing yield patterns, losses to evapotranspiration and groundwater recharge. He would also presumably want to know about the effects of temperature on a snowpack and on rates of snowmelt runoff. He would also be expected to know about the impact of high intensity and long duration storms on erosion and sedimentation and how to minimize deterioration of water quality and limit flooding.

Figure 3.3m

Estimated Average Annual Precipitation (mm)
Kananaskis District

DERIVED FROM EXISTING PRECIPITATION RECORDS (INCLUDING SNOWFALL), CORRELATED WITH ELEVATIONAL, PHYSIOGRAPHIC AND VEGETATIVE INFORMATION, AND CHECKED WITH STREAMFLOW RECORDS.



SCALE = 1 : 250,000

In the Kananaskis District all of the above characteristics come together to produce an extremely variable and complex association between climate and hydrology. For example, the dominant form of precipitation is snow at the higher elevation (exceeding 75 percent) while rain dominates low elevation valley locales. Seasonally, the higher elevation areas receive their maximum precipitation in winter, while valley areas receive their maximum in summer. Almost twice as much total precipitation, 127 mm (50.0 inches) falls at upper elevation than lower valley sites, and even this is probably exceeded at the highest sites along the Continental Divide. Research has been conducted on evapotranspiration losses in the District and estimates based on elevation, vegetation and soils information can be developed. Potential evapotranspiration will vary from a high of 457 mm to 508 mm (18 to 20 inches) in the lower valley areas to a low of 127 mm (5 inches) at high elevation areas. Actual evapotranspiration is more difficult to estimate, but it is probable that deficits which occur in some years in lower valley areas such as the Evans-Thomas Creek confluence would negate any runoff. Even in upper slope areas, drier than normal conditions can result in deficits with far reaching affects on water yield. Thus the negligible increases in water yield from Marmot Creek after forest treatment are probably due as much to losses from wet years to make up for previous dry years, as it is to Chinook effects.

A watershed manager must also concern himself with potential flooding hazards and in the Kananaskis District this would most likely occur in the late spring when much of the remaining snowpack is at or near the melting point. The addition of rain on the snowpack would release a large amount of runoff sooner than expected and depending on the condition of the soil, would contribute runoff directly into the reservoirs. In the Kananaskis District

much of this phenomena would occur in the spring (ie. April) when the reservoirs are near their lower stage of the year. Thus a built in measure of flood control is available in most seasons, until the reservoirs are full, at which time intense rain storms of long duration would necessitate the regulation of these reservoirs to limit flooding and associated bank and bed scouring.

Regulation of the lakes and river system in the Kananaskis District by the watershed manager is carried out in response to external demands for power and downstream flow regulation. Only under conditions where flooding may occur due to heavier than normal runoff, does the regulation of water levels and flow respond to internal demands. Increased use of the Kananaskis District by recreationists will create the need for better information on climate variables and their influence on the hydrology of the area. Internal water-based recreational activities are identified in Kananaskis Provincial Park literature as providing a focus for recreational development of this region. The following section examines the physical hydrology of the District and discusses how the lakes and rivers have been and are being managed.

Chapter 4

4.0 HYDROLOGIC ANALYSIS

It is the intent of this Chapter to analyze and describe the water supply characteristics of the Kananaskis District. An examination of groundwater storage and reconstruction of the natural runoff patterns will form the introduction for the ensuing discussion on streamflow and lake level variations. Much of the information presented in the previous Chapter concerning precipitation/evapotranspiration relationships and vegetation and soil patterns, is used here to help explain regional runoff characteristics. Historic and contemporary flow records are analyzed to provide the sub-basin and total basin water yield patterns.

Of particular interest to a watershed manager is how much streamflow is available at any given time, how much useable surface storage is present, and how each of these variables is affected by nature and man's actions. A detailed look at the contrast between natural streamflow and lake level conditions, and the controlled hydrologic conditions of the post-1932 era, will comprise a major portion of this Chapter. The contemporary patterns of streamflow and lake levels reflect the present management orientations. Therefore, a discussion of contemporary hydrologic characteristics will help provide a basis for the discussion to follow in Chapter 5 on water management alternatives.

4.1 GROUNDWATER

4.1.1 Hydrogeology

Groundwater in the District is thought to occur generally under water table conditions. The groundwater reservoir is recharged in spring and early summer by infiltration from snowmelt and rainfall,

and is gradually depleted during late fall and winter as it supplies baseflow to surface streams. The relief of the water table generally follows, but is more subdued than, the relief of the ground surface (Osborn and Jackson, 1974). In Marmot Creek, the main stream and its tributaries simulate V-shaped drains when the water table intersects with the ground surface. Elsewhere the slope of the water table decreases more rapidly than the overlying ground surface, and in each of these cases, a spring or boggy area is developed (Stevenson, 1974).

The presence of large volumes of groundwater stored in certain surficial soils has been inferred by Laycock (1957a, 1958) and demonstrated by Stevenson (1967) in the Marmot Creek basin. Surficial deposits plastered along the sides of the Marmot Creek valley (and for most of the Kananaskis Valley) consist of scree and talus, and colluvium, often in conjunction with glacial till in the form of lateral moraines. The scree and talus have a high detention storage capacity (Laycock, 1957a, 1958), and those that are on north facing slopes often have a large ice-cemented matrix. This is built up during spring thaw periods when daytime melting results in entry of snowmelt waters into the still cold colluvial masses and night-time freezing results in their being retained. Retention in summer can be prolonged by cool temperatures resulting in lower releases during this period.

Glacial tills have low hydraulic conductivities (Stevenson, 1967) due to their poorly sorted nature, and as a result are generally saturated or partly saturated providing considerable retention storage for large volumes of water. Present along the river valleys are lag boulder deposits and alluvium. Some of these deposits form part of the riparian and telluric groundwater system.

The significance of bedrock in directing groundwater flow has been investigated by Stevenson (1967). Groundwater flow in rock is

a function of intergranular porosity and rock fractures. Bedrock underlying much of the Kananaskis District consists mainly of layers of sandstone, siltstone, shale, quartzite and limestone, although the latter usually underlies ridges and peaks due to its more resistant nature (Osborn and Jackson, 1974). The former rocks are all Mesozoic in age, except quartzite, and are generally cemented with negligible intergranular porosity; however, they are all fractured to some extent. Many large scale fractures occurring in the District are thrust faults which act as hydraulic barriers. Normal faults (termed by Stevenson, undated report, 'block faults') often feature an open space along the fracture and act as hydraulic sinks.

Quartzite is irregularly jointed but it is believed that the joints probably close at depth, rendering the rock rather impermeable and hydraulically disconnected to surficial deposits (Osborn and Jackson, 1974). Overlying the quartzite are the Spray River siltstones which also show jointing but piezometer tests show that they are also disconnected to the active groundwater reservoir (Stevenson, 1967). Shales of the Fernie and Kootenay formations are quite fractured and piezometer tests show these to be hydraulically connected to the active groundwater reservoir (Stevenson, 1967). Other sandstone or conglomerate units commonly underlie steep surface slopes, and it is thought that most precipitation here probably converts to runoff rather than infiltrating (Osborn and Jackson, 1974).

In summary, most storage and movement of groundwater within bedrock occurs in fractured shales of the Kootenay and Fernie formations. Coarse talus and colluvial materials have a high detention storage capacity, although retention storage varies with temperature and position. Poorly sorted glacial tills provide considerable retention storage for large volumes of water.

4.1.2 Groundwater Discharge Phenomenon

The nature of groundwater flow in the Kananaskis District is highly variable on a spatial and temporal basis. Stevenson (n.d.), in his analysis of groundwater flow systems for Marmot Creek, adopted the Chernaya classification for identifying groundwater discharge phenomenon. Descending groundwater discharge is defined as groundwater that reaches the stream after discharging at some higher elevation. Alternatively, ascending groundwater discharge reaches the stream area below the water line of the stream from a flow system hydraulically connected with the stream. In Marmot Creek, and for much of the Kananaskis District, most groundwater discharge phenomena observed above the valley bottoms are of the descending type (Stevenson, 1967).

For example, descending groundwater discharge phenomenon include contact springs; seepages,mudflows, earthflows and slumps; boggy areas and hummocky ground; and the presence of phreatophytic plants. Contact springs occur where impermeable material prevents the continued downward percolation of groundwater through permeable material, thus deflecting water to the surface. Measured flow rates in Marmot Creek vary seasonally from a high of 1,800 litres/minute (400 gallons/minute) during the time period immediately following spring runoff, to less than 1.0 litres/minute (0.2 gallons/minute) during the dry, low-runoff fall-winter period (Stevenson, 1967). Heavy rainfalls, or rainfalls of long duration, can rejuvenate springs during prolonged summer droughts, although the volume and rate of flow would be considerably less during the peak runoff period.

Where discharge occurs from minute pore spaces instead of along bedrock contacts, the discharge takes the form of seepage. Seepage is associated with an increase in pore pressures within the surficial materials, and may result in mudflows, earthflows or slumps. These processes of mass movement result in small amphitheatre-like bowls (Stevenson, n.d.) around seepage areas on valley sides. Evidence

of seepage can be found where forests have been cut, such as in Marmot Creek and Smith-Dorien Valley, and where main roads have been cut into slopes.

Boggy and hummocky ground are found within local depressions in descending groundwater discharge areas, and owe their presence to the low permeability of underlying materials. Boggy ground can be found, particularly in wet years, in the broad valley east of Lower Kananaskis Lake and in some of the higher, drift-filled bedrock basins. Hummocky ground is often found around the perimeter of boggy areas and is attributed to the compaction of organic soils and clump-like growths of vegetation. These conditions are present in the pass between Pocaterra Creek and the Elbow River and in the vicinity of Mud Lake and Burstall Lakes, and in the Highwood Pass.

The presence of phreatophytic plants provides one of the best indicators of permanent, excessive soil moisture conditions. In areas of descending groundwater discharge, hydrophytic plants occur in strips along valley sides and as 'halos' around points of concentrated groundwater discharge. Where abrupt changes occur in soil moisture along the boundary between two rock types with markedly different hydraulic properties, there is always a resultant change in associated plant types. Stevenson (1967) has noted those plant types which characterize areas of groundwater discharge in Marmot Creek, (see Table 4.1a).

4.1.3 Groundwater - Streamflow Relationship

Attempts at quantifying the relationship between groundwater and streamflow is part of the on-going research in the Marmot Creek experimental watershed. For the period August, 1965 to August, 1966 approximately 34 percent of streamflow during the measurement period was baseflow contributed by groundwater using groundwater budget

Table 4.1a

Typical Plant Association in Groundwater Discharge Areas
in the Kananaskis District

a.	Tree types:	Black Poplar (Populus trichocarpa) White Spruce (Picea glauca) Water Birch (Betula occidentalis) Willows (Salix spp.)
b.	Shrubs:	Swamp Birch (Betula pumila var. glandulifora) Willows (Salix spp.) Wild Gooseberry (Ribes hirtellum)
c.	Forbs:	Cow Parsnip (Heracleum laratum) Delphinium (Tall larkspur - Delphinium menziei spp.) Baneberry (Actaea rubra) Heart-leafed arnica (Arnica cardifolia)
d.	Grasses, Sedges and Mosses:	Timothy (Phleum spp.) Sedge (Carex spp.) Equisetum (Equisetum spp.) Club Moss (Hycopedium spp.)

In especially boggy areas:

a. Tree types are small white spruce at high altitudes and Black spruce (Picea mariana), Black poplar and Willows at lower altitudes.

b. Shrubs are swamp Birch and Willow.

c. Forbs are mainly bog orchids, elephant head (Pedicularis gaoenlandica) and wintergreen (Pyrola spp.)

d. Marsh grasses, sedges and horsetail are present along with a very thick cover of club mosses.

Source: Stevenson, undated report

techniques (Stevenson, 1967). An estimate of the maximum subsurface reservoir was calculated from an examination of the relationship between streamflow (N), mean daily streamflow ($\overline{N}$), and the total change in subsurface storage (ΔW).

The relationship:

$$\Delta W_{(mm)} = 2154e^{-8.11\ \overline{N}}\ \Delta N$$

produces an exponential hydrograph recession shown in Figure 4.1a. By assuming that when N=0 then W=0, the use of small values of both W and N produces:

$$W_{(mm)} = 265.6\ (1 - e^{-8.11\ N})$$

which is illustrated in Figure 4.1b. This relationship indicates a maximum reservoir capacity of 265mm (10.5 in.) which is reached at a flow of approximately 0.71 cms (25 cfs) (Storr, 1974b). In theory this provides workable estimates regarding flow for flood forecasting applications. For example, at N=0.4 cms (14 cfs), only 10 mm (0.4 in.) of storage would be available before saturation of the groundwater reservoir would occur and any excess would become direct surface run-off. Similarly if N=0.2 cms (7 cfs), then approximately 52 mm (2.0 in.) of storage are available before there would be any surface runoff (Storr, 1974b). In practice, however, capacity by this criterion is usually reached in June due to the contribution of snow-melt and heavy rainfalls. During the rest of the year, storage is below capacity and the highly permeable nature of the surficial materials minimizes the chance for direct flow into stream channels.

Storr's (1974) results show that an average annual change in subsurface groundwater storage of 49 mm (1.9 in.) is significant in influencing seasonal and annual streamflow conditions. A later study (Storr, 1977) revealed that there were variable sub-basin differences in storage change for both seasonal and annual time periods. It was concluded that the differences between W, N and $\overline{N}$ for each sub-basin

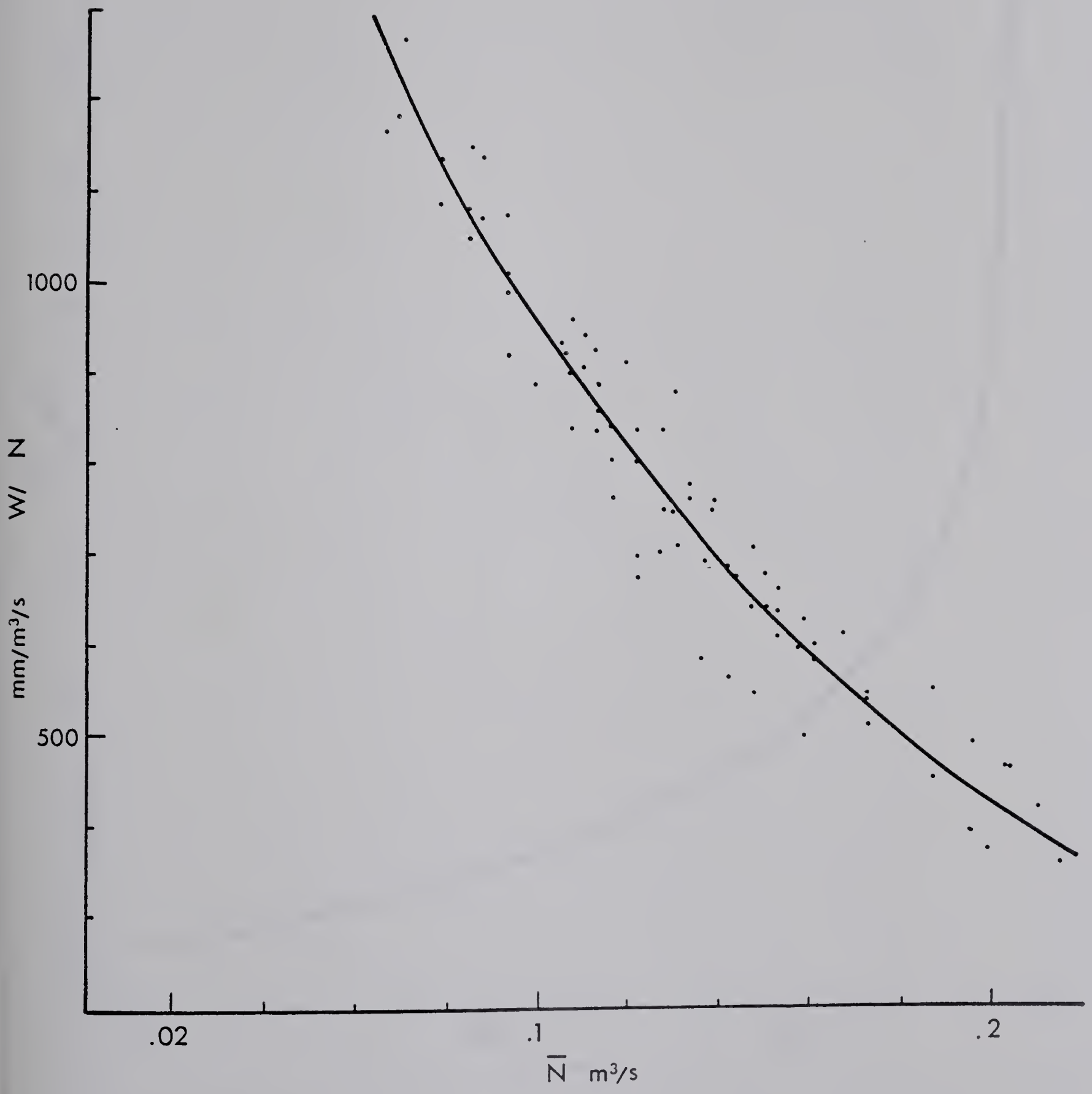


Figure 4.1a Relationship between W, N and $\bar{N}$, at Marmot Creek.

Source: Storr, 1974.

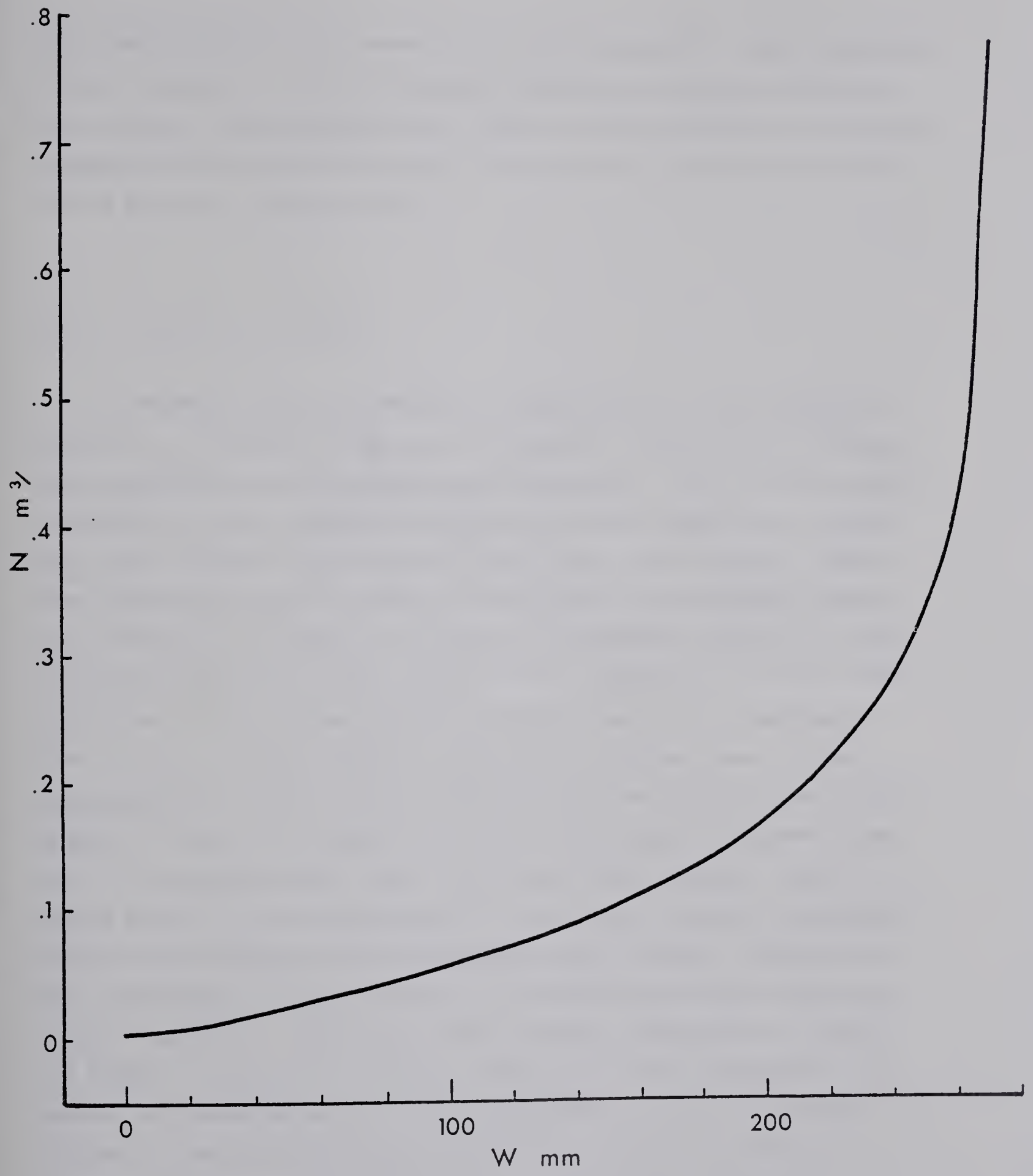


Figure 4.1b Relationship between subsurface storage (W) and streamflow (N) at Marmot Creek.

Source: Storr, 1974b

were due largely to the geomorphic characteristics of each sub-basin. Further studies on some of the more important climatic variables, particularly evapotranspiration, will test the validity of the above assumption, and certainly qualify the large net errors which Storr (1977) had not commented upon.

4.1.4 Groundwater Summary

In summary, the information on groundwater in the Kananaskis District, its nature and extent, is somewhat inconclusive although some generalized relationships are recognized. It is believed that groundwater occurs generally under water table conditions, following a more subdued relief pattern than the ground surface. While some groundwater may be stored in fractured (not permeable) shales and therefore be linked to the active groundwater reservoir, little groundwater potential exists for the less permeable siltstones and quartzites. By far the greatest potential source of groundwater lies in the surficial deposits plastered along the lower slopes, particularly the tills and in certain areas the colluvial materials. Depths of over 30.5 m (100 ft.) of till are common in Marmot Creek and it is suspected that there are larger drift basins, like the valley east of Lower Kananaskis Lake, which may contain significant amounts of groundwater in predominantly dead storage. Evidence of the significance of groundwater to streamflow has been documented through research. Similarly, there are many indicators of active and hightly variable groundwater influence on the geomorphic and vegetative characteristics of the Kananaskis District. Further studies of these relationships may aid in developing estimates of evapotranspiration for later use in predicting patterns of precipitation and runoff in ungauged areas.

4.2 RUNOFF VARIATIONS

4.2.1 Seasonal Patterns

The seasonal variations in natural runoff can be deduced from precipitation, lake level and streamflow records. Much of the rainfall received in the summer months is used in evapotranspiration. Since snowfall makes up about 75 percent of the total precipitation in the mountains and foothills of the Eastern Slopes, it follows that the snowmelt period is responsible for most of the runoff. Prior to 1933, when regulation of the watershed began, maximum daily runoff values were achieved during the month of June in 17 out of 22 years, with the earliest maximum occurring on June 1st, while the latest maximum was recorded on September 1st. After 1933, regulated runoff values reflect, on average, lower maximum daily values by almost half, and a seasonal range of maximum daily values from February 7th to August 6th.

Table 4.2a is a list of the percentage values of natural runoff on a monthly basis before regulation. The snowmelt runoff component supplies,on average, over 75 percent of the annual total in the months of May through August. June is the peak runoff month; however, it also has the greatest range in percent annual runoff. This is due, in part, to the pressure systems and air masses which influence regional temperatures and precipitation characteristics, thus resulting in early, late and sometimes intermittent spring melt periods. June is also the month of maximum precipitation for the front ranges and foothill areas, while back range and divide areas experience a regime similar to marine west coast areas, with a winter maximum as evidenced by Lake Louise precipitation records. Since over 75 percent of the annual precipitation falls prior to the month of peak runoff in the back range areas, the contribution of rain to the major runoff period is minimal, except perhaps during a

Table 4.2a

Percent Distribution of Normal Runoff by Months for the Years 1912 to 1932 Inclusive, Kananaskis District

Percentage of Annual Natural Runoff in Each Month

YEAR	J	F	M	A	M	J	J	A	S	O	N	D
1912	1.8	1.7	1.7	1.7	6.4	21.1	26.7	19.0	8.7	5.0	3.4	2.7
1913	2.1	2.1	1.7	2.2	6.1	21.3	15.6	15.9	12.3	6.3	3.8	2.8
1914	1.9	2.0	2.1	2.3	9.9	22.6	23.3	13.2	8.2	7.4	4.3	2.7
1915	1.1	1.7	1.5	2.3	10.7	21.9	23.3	15.7	9.4	5.6	3.4	3.1[h]
1916	1.5	1.1[l]	1.4	2.0	4.2[l]	29.3	26.6	13.8	10.7	4.6	2.9	1.9
1917	1.7	1.1	1.9	1.8	10.4	28.5	24.0	13.7	8.5	5.4	3.1	-
1918	-	-	-	2.4	5.7	30.2	21.3	16.4	10.8	7.1	3.5	2.5
1919	1.8	1.1	1.1[l]	2.7	14.2	22.5	16.7	19.2	10.1	5.0	2.9	2.8
1920	2.1	2.2	1.7	1.7	6.0	19.3	32.4[h]	15.6	8.6	4.9	2.9	2.4
1921	1.8	1.8	1.7	2.3	13.6	26.6	10.8[l]	14.3	7.0	4.4	3.3	2.4
1922	2.0	1.8	2.3	2.2	11.8	28.5	17.6	14.3	9.7	5.6	2.7	1.6
1923	1.0[l]	1.1	1.4	1.5[l]	5.4	39.8[h]	20.0	12.8	8.0	4.7	2.8	1.5
1924	1.5	1.9	1.8	1.9	10.5	22.0	21.1	20.3[h]	9.4	4.2	3.0	2.3
1925	2.0	1.8	1.5	3.1	14.2	24.9	16.9	14.2	9.6	5.9	3.4	2.4
1926	2.9	2.6	2.2	3.7[h]	7.8	15.6[l]	18.8	11.9	17.9[h]	10.8[h]	6.3[h]	-
1927	-	-	-	2.4	6.2	32.2	22.3	14.3	11.4	7.1	3.2	0.8[l]
1928	1.5	1.7	2.1	2.3	14.6[h]	27.5	21.7	12.5	6.8[l]	4.3	2.9	2.0
1929	2.3	1.8	2.0	1.8	10.2	36.7	16.5	11.6[l]	7.2	5.0	2.8	2.1
1930	1.4	1.8	1.8	3.3	11.2	26.4	21.6	13.9	9.1	4.6	2.6[l]	2.1
1931	3.0[h]	2.9[h]	3.0[h]	2.7	11.3	27.6	19.0	14.8	10.5	5.1	-	-
1932	-	-	-	-	14.3	40.5	15.9	11.9	7.8	4.0[l]	3.0	2.5
MEAN	1.9[x]	1.7[x]	1.8[x]	2.3	9.7	26.9	21.1	14.7	9.6	5.6	3.3[x]	2.3[x]

x Estimates due to incomplete data
l Lowest Value for month
h Highest Value for month

Source: Environment Canada, 1979

particularly wet year. Snowmelt is definitely more consistent and reliable in terms of providing the major portion of runoff.

Smaller streams, such as Marmot Creek and Pocaterra Creek, also exhibit a similar pattern in runoff characteristics discussed above for the entire Kananaskis District. Rapid increases in runoff in May and June are followed by a levelling off during late June, and a general decline in August which continues through to October when precipitation inputs to direct runoff diminish (see Figure 4.2a).

The low runoff season which characterizes winter, occurs because precipitation is stored in the form of snow. The base flow which dominates this period is accounted for almost entirely by groundwater discharge, supplemented by available detention storage in lakes. While this flow is relatively constant, it does decline slightly, reflecting the diminishing groundwater contribution. This trend is evident in smaller streams like Marmot Creek, and is even discernable for major rivers like the Kananaskis. The relatively constant values of percent natural runoff during the winter period help to confirm this.

Regulation of the lakes and major river systems has brought about a number of changes in runoff characteristics, including changes in the seasonal patterns. While snowmelt runoff still occurs at a natural rate, and no attempts have been made to control it for regime purposes, aside from small basin experiments, the seasonal pattern of runoff, as measured at the major stream gauge at the Districts' entrance, has changed. The creation and enlargement of storage reservoirs in 1933, 1942, 1947 and 1955 provided a degree of control which improved with each additional increase in storage. Table 4.2b lists the percent values of regulated runoff on a monthly basis after regulation began. Details of the increases in storage are given in section 4.4.2.

Marmot Creek 1963 - 1978
Mean Seasonal Runoff from Mean Monthly Discharges



Pocaterra Creek 1931 - 1941
Mean Seasonal Runoff from Mean Monthly Discharge

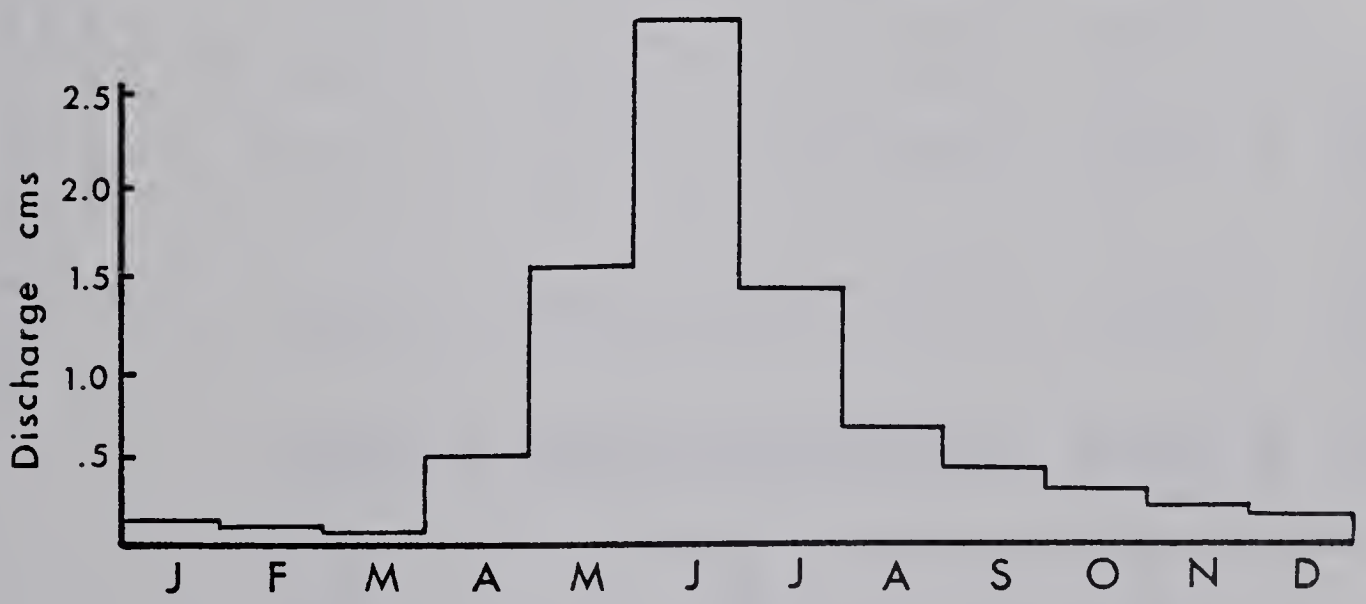


Figure 4.2a Seasonal Variations in Runoff of Two Small Unregulated Streams

Source: Environment Canada, 1977

Table 4.2b

Percent Distribution of Regulated Runoff by Months for the Years 1933 to 1961 Inclusive, Kananaskis District

Percentage of Annual Regulated Runoff in Each Month

		J	F	M	A	M	J	J	A	S	O	N	D
	1933	2.9	1.4[l]	1.6	1.9[l]	11.6	29.8[h]	21.4	11.0	7.5	4.3	3.3	3.1
INITIAL	1934	3.6	4.8	2.5	5.5	17.3	20.2	14.8	11.2	8.5	3.7	3.3	4.8
CONSTRUCTION	1935	3.4	3.0	2.3	2.3	6.7	24.4	24.0[h]	13.5	4.5	4.5	4.6	6.7
PERIOD	1936	4.9	4.5	1.9	3.3	12.2	22.5	17.0	11.2	4.6	3.9	6.0	7.9
	1937	4.4	2.6	1.5[l]	1.9	7.9	20.6	22.8	16.6	7.7	5.8	5.4	2.8[l]
	MEAN	3.8	3.3	2.0	3.0	11.1	23.5	20.0	12.7	6.6	4.4	4.5	5.1
	1938	2.4[l]	1.6	2.3	2.7	14.2	28.7	20.7	11.3	5.7	4.7	2.0[l]	3.6
	1939	3.3	5.4	4.0	2.8	8.7	18.0	16.9	13.5	11.9	5.5	4.6	5.6
	1940	4.8	5.2	5.8	3.4	11.2	14.0	11.3	10.6	13.8[h]	7.2	6.6	6.0
	1941	4.9	4.8	4.3	3.9	7.6	14.2	14.1	14.1[h]	12.3	8.3[h]	5.6	6.0
	1942	6.7	5.4	3.9	3.5	19.4[h]	22.7	17.1	9.9	7.5	5.6	4.6	9.2
	1943	3.7	8.4	8.1	6.2	7.4	14.2	16.0	6.9	4.2	3.3	6.5	7.4
	1944	9.6	8.7	8.1	5.9	8.2	14.0	9.7	9.7	6.5	5.6	5.5	8.5
CONSTRUCTION	1945	5.5	5.6	4.7	3.7	8.0	21.3	16.3	7.8	6.0	4.9	8.2	8.0
PERIOD	1946	3.2	3.0	2.7	2.6	7.5	10.3	5.5	3.2[l]	3.3	2.7[l]	4.2	4.6
	1947	7.3	6.4	5.1	5.2	10.5	18.8	11.5	4.0	7.4	8.3	7.6	7.8
	1948	6.1	4.4	5.2	5.6	14.9	20.4	10.1	7.6	4.6	4.1	4.7	4.7
	1952[x]	-	4.5	-	12.9[h]	13.7	16.0	15.3	9.4	4.8	4.4	9.2	9.8
	1953	6.7	5.5	6.9	7.3	8.2	20.7	16.2	7.0	4.5	3.4	6.7	6.9
	1954	7.1	3.0	6.3	6.8	8.2	17.6	16.6	7.4	5.7	5.7	7.8	7.6
	1955	8.6	8.9	7.9	9.0	4.7[l]	17.5	12.0	4.9	3.1	3.7	9.0	12.9[h]
	1956	12.3[h]	11.7	9.8	3.5	8.4	10.2	12.2	6.0	7.9	3.8	7.7	6.6
	1957	11.0	11.1	11.0	12.5	11.2	9.2[l]	5.3[l]	3.9	5.2	6.4	3.4	9.9
	1958	8.4	13.7	12.2[h]	8.6	6.1	9.9	8.2	3.6	2.9[l]	4.8	9.9[h]	11.8
POST	1959	10.8	17.2[h]	5.9	5.6	4.8	13.8	8.5	6.0	5.2	6.1	6.1	10.0
CONSTRUCTION	1960	10.2	9.0	9.9	3.8	7.6	11.2	10.0	9.4	5.8	4.6	9.2	9.4
PERIOD	1961[t]	6.6	7.0	7.2	5.4	8.5	16.5	7.8	7.5	6.8	7.5	9.3	9.9
	MEAN	9.4	11.6	9.2	7.2	7.6	12.1	8.0	6.1	5.2	5.9	7.6	10.2

x 1949 - 1951 Data Incomplete
l Lowest Value for Month
h Highest Value for Month
t Last Year of Use for Recording Flow Gauge

SOURCE: Environment Canada, 1979

In the first 5 years after the initial development of Upper Kananaskis Lake in 1932, the percentage of runoff by month declined between 1 and 3 percent during the high-runoff summer period and rose a similar amount during the winter months, when compared to natural runoff figures. With each additional increase in storage, the variation in seasonal runoff between summer and winter also decreased. After 1956, the percentage of monthly runoff during the summer months declined to less than 50 percent of the natural runoff patterns, while winter flows were increased from two to five times the natural monthly flow.

The change in seasonal runoff patterns due, in part, to storage developments, has also brought about changes in total runoff, diurnal runoff patterns and other characteristics. These changes will be looked at in more detail in Section 4.4.3.

4.2.2 Spatial Patterns of Runoff

The spatial variations in natural runoff can be explained in part by the way in which physiography and vegetative cover combine to influence aspects of the hydrologic cycle. In the Kananaskis District, these variations can be deduced by careful mapping of streamflow-generated runoff values, adjusted to reflect changes in physiographic and vegetative characteristics. The procedures used are similar to those adopted by the U.S. Water Resources Council, and used by the U.S. Geological Survey in various Framework Studies (ie. Idaho, State Water Plan; Idaho Water Resources Inventory, 1969). In this study, natural streamflow records were used to generate sub-basin and total basin runoff values. Although the Burstall Creeek area has been diverted into the Spray drainage basin, the original calculations were performed with natural flow data from this area and therefore it has been left in the map. Isolines were then plotted for

each sub-basin, indicating the approximate depth of runoff in millimetres, and areal values of runoff were planimetered to ensure close agreement with the generated mean value. The end result is a product not unlike a topographic map, with isolines representing the approximate mean depth of runoff (see Figure 4.2b).

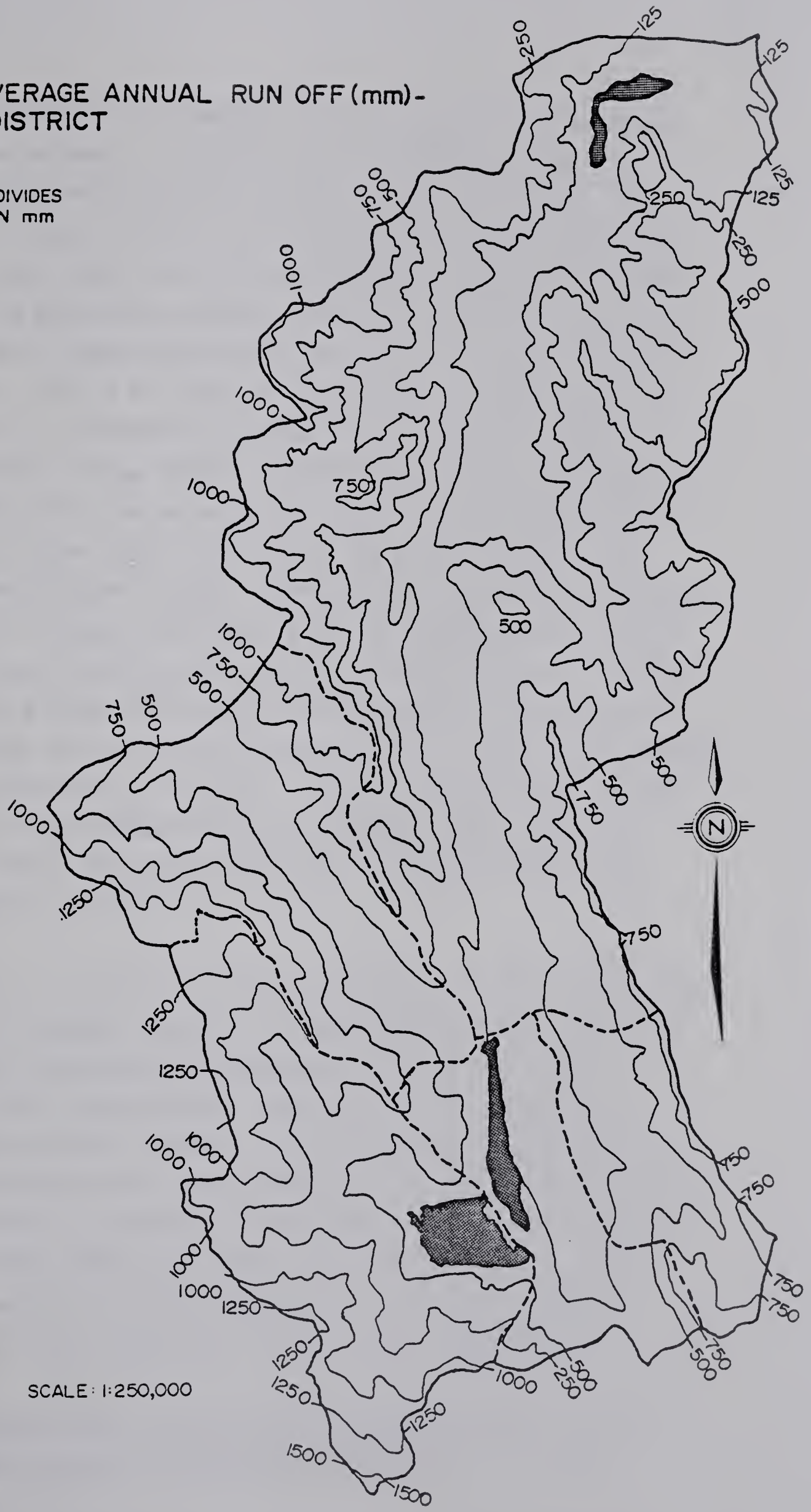
The relative positioning of the isolines was determined using maps of elevation, surficial geology and vegetation. Recent studies (Bayrock and Reimchen, 1977; Jackson, 1977) have provided excellent maps and descriptions of surficial deposits for the Kananaskis District. The use of air photos, and field checking in the summer of 1978, helped to verify the broad patterns that are depicted. The importance of surficial deposits in their detention and retention storage characteristics has been previously noted (Laycock, 1957a, 1958; Osborn and Jackson, 1974). The distribution of vegetation has been mapped according to forest cover type (Alberta, Energy and Natural Resources, 1976), and also using an ecohierarchical classification (Jacques and Legge, 1974). The presence of vegetation effectively reduces the amount of runoff due to transpiration losses. Approximating evapotranspiration from indirect sources is not a desireable method, however, short-term class A pan measurements and information from various stations on precipitation and temperature correlated with physiographic and vegetative relationships, can be used as a basis for estimates. Such procedures have been used to develop the estimates for approximate mean annual distribution of runoff.

The irregular nature of the isolines would suggest that cartographic smoothing has not been employed, yet the scale of the map dictates that some generalization is present. Nevertheless, changes in vegetation and physiography produce patterns which reflect their combined influence on runoff.

FIGURE 4.2b

ESTIMATED AVERAGE ANNUAL RUN OFF (mm)-
KANANASKIS DISTRICT

---- WATERSHED DIVIDES
ALL VALUES IN mm



A number of trends are apparent in the map, and the following discussion is an attempt to highlight some of these. Those areas contributing high runoff relative to precipitation received are characterized by high elevation, bare rock areas, often exhibiting steep slopes. Such areas can be found along the Continental Divide, and the Spray and Kananaskis Ranges separated by Smith-Dorien Creek as well as the Opal Range which marks much of the eastern boundary of the District. Due to the lack of vegetation, evapotranspiration losses would be low, probably less than 125 mm (5.0 in. approx.) especially on north facing slopes. South facing slopes would receive higher insolation and thus potentially higher values of evaporation, but lower temperatures due to high elevation would minimize the actual evapotranspiration losses. Runoff values in excees of 1500 mm (60.0 in. approx.) appear reasonable given the physiographic nature of the Divide areas, particularly near the Mangin Glacier. Although there is so little proof with which to substantiate this reasoning, streamflow records for the Upper Kananaskis Lake drainage area suggest that at least this much is possible. Lower values of runoff on the west slope of the Opal Range are due to markedly lower values of precipitation than is received along the Continental Divide and Kananaskis Range to the west.

The decline in runoff which occurs generally with a decrease in elevation is the combined result of lower precipitation, increased moisture storage capabilities of downslope materials, notably colluvium and till, and increased vegetative cover resulting in higher evapotranspiration values. Local variations in moisture storage and vegetative cover are responsible for some rather striking variations in runoff, particularly along the base of slopes where raw colluvium often grades into till, providing not only a variable detention and retention storage capability, but also a variable vegetative cover, thus potentially higher evapotranspiration.

It is estimated that the spruce/fir and mixed spruce and pine on the sub-alpine slopes of Smith-Dorien Creek result in evapo-

transpiration values of 250 mm (10.0 in. approx.) with some lower valley and south facing slopes experiencing slightly higher values. Similar stands of mature spruce, alpine fir and pine can be found around Upper Kananaskis Lake, Marmot Creek and Ribbon Creek. Coincidentally, these stands are supported by variable thicknesses of glacial till, associated, in places, with a thin veneer of colluvial material. The unsorted but highly variable textures characteristic of glacial tills, provide good detention storage for runoff from higher levels (Laycock, 1959). Retention storage for plant use is usually high; therefore, runoff from these areas tends to be low. Thus there is a marked contrast in runoff regimes during the transition from steep colluvial slopes to valley and lower slope till deposits, and this transition is generally reflected by a decrease in runoff depicted in the map.

Where precipitation values are known, and vegetative cover is stable, the runoff characteristics can be fairly well established. Thus the valley patterns, which show relatively low runoff values correlate well with climatic and physical/vegetative cover variables. For example, the large valley area to the east of the Kananaskis Lakes is a large drift basin, occupied by varying thicknesses of tills in association with glaciofluvial deposits (Osborn and Jackson, 1974). Combined, these deposits provide a significant amount of detention storage for runoff from adjoining slopes (Laycock, 1958). The vegetation cover is predominantly lodgepole pine throughout much of the valley, often in conjunction with small stands of spruce or sub-alpine fir; however, at lower elevations pine can be found mixed with aspen, or completely absent. Thin deposits of alluvium over gravels found in close proximity to the river, support mainly grass and willow scrub, since moisture retention storage capacities are not adequate in these shallow deposits to support extensive tree growth (Laycock, 1958). The precipitation characteristics described and mapped in Chapter 3 show valley locations generally receiving less

precipitation than upland areas, although location and other factors combine to produce variations in this pattern. Subsequently, the Mud Lake area of Smith-Dorien valley receives about 890 mm (35.0 in.) of precipitation, but high retention storage in local tills and glacio-fluvial deposits and the presence of a mature spruce forest cover, mixed with some immature spruce and pine, would result in approximate evapotranspiration of 375 mm (15.0 in.), which is physio-ecologically similar to Mount Creek, leaving about 500 mm (20.0 in.) for runoff.

Similarly,the main Kananaskis Valley east of Lower Kananaskis Lake receives between 625 mm (25.0 in.) of precipitation near the mouth of Boulton Creek, and 760 mm (30.0 in.) of precipitation on the lower western slopes of the Elk and Opal mountain ranges. Again, local tills and glacio-fluvial deposits provide high retention storage and support extensive stands of lodgepole pine and mixed immature spruce-sub-alpine fir-pine associations. An estimated evapotranspiration of 375 mm (15.0 in.) is not unreasonable, and would result in runoff values of 250 mm (10.0 in.) or less in the valley proper, and 375 mm (15.0 in.) or less on the lower west facing slopes.

Precipitation in the vicinity of Evans-Thomas Creek is less than that received by other valley stations (Poliquin, 1968). Reasons for this are not clear; however, the valley is too far from the Continental Divide to benefit from carryover precipitation and is in the shadow of the front ranges to the east. The area is also protected to some extent from incursions of upslope winds from the Bow Valley to the north. Glacial till comprises most of the upper valley stream locations, whereas glacio-fluvial and alluvial materials are present in a large fan-like deposit at the streams confluence with the Kananaskis River. As a result, retention storage capabilities are very good and the stable vegeta-tive cover of spruce and pine in the upper valley and mixed conifer-

ous-deciduous associations at the confluence, suggest that evapotranspiration estimates of 375 mm (15.0 in.) and 450 mm (18.0 in.) respectively are not unreasonable in normal years. Therefore runoff in the middle to upper valley locations would average 250 mm (10.0 in.) or less, while less than 125 mm (5.0 in.) would be possible at the confluence. In very dry years it is likely that deficits would be large enough in summer such that actual evapotranspiration could be well below 250 mm (10.0 in.).

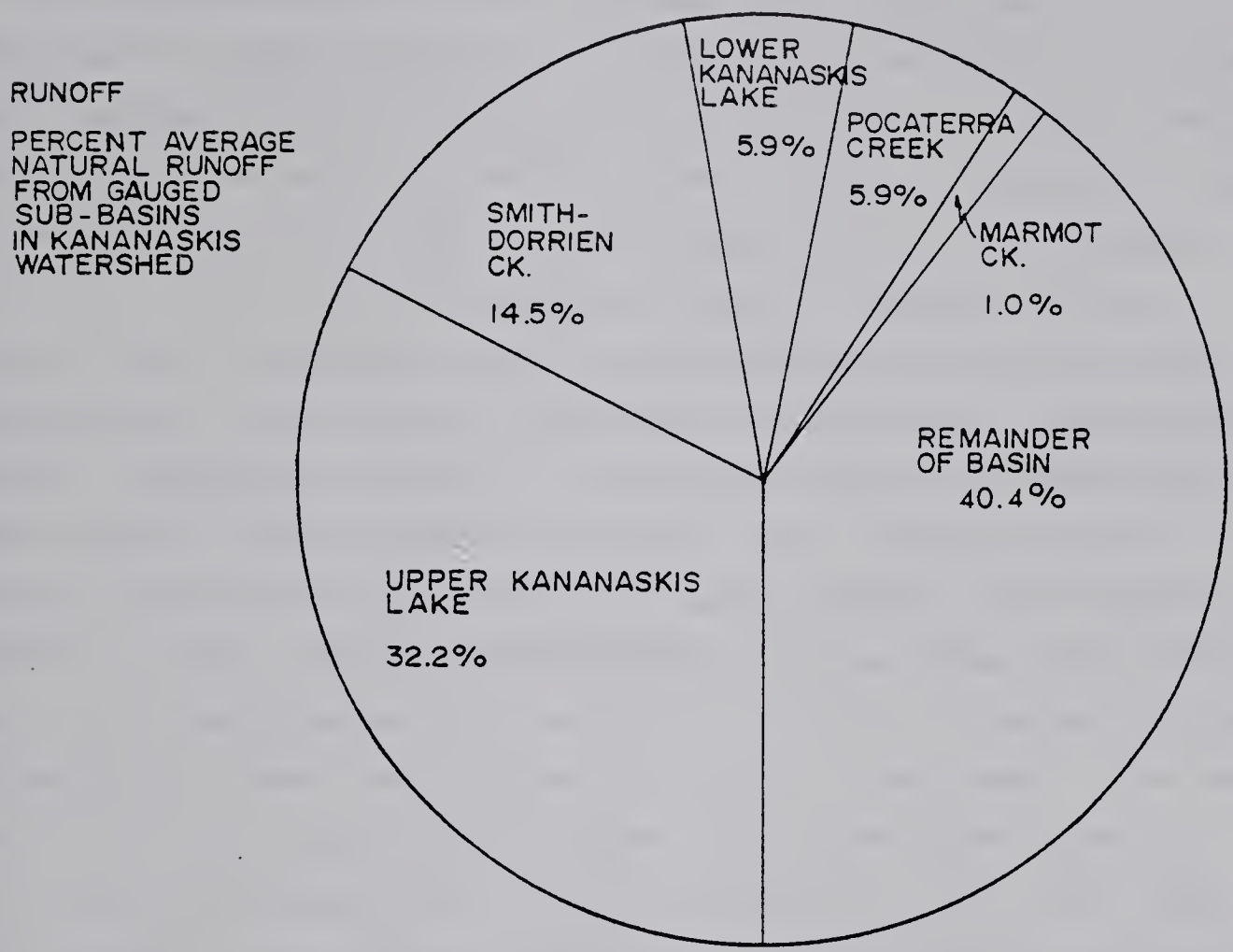
Runoff data from the Marmot Creek basin, is perhaps the best for any area in the Eastern Slopes. Precipitation over this 9.4 sq. km. (3.6 sq. mi.) watershed is quite variable, yet averages about 875 mm (35.0 in.). Evapotranspiration estimates derived from field measurements and energy budget calculations show an average loss of approximately 425 mm (17.0 in.) (Storr, 1974). Thus runoff from the basin approaches 450 mm (18.0 in.). The physiographic and vegetative cover characteristics, described earlier, support these estimates.

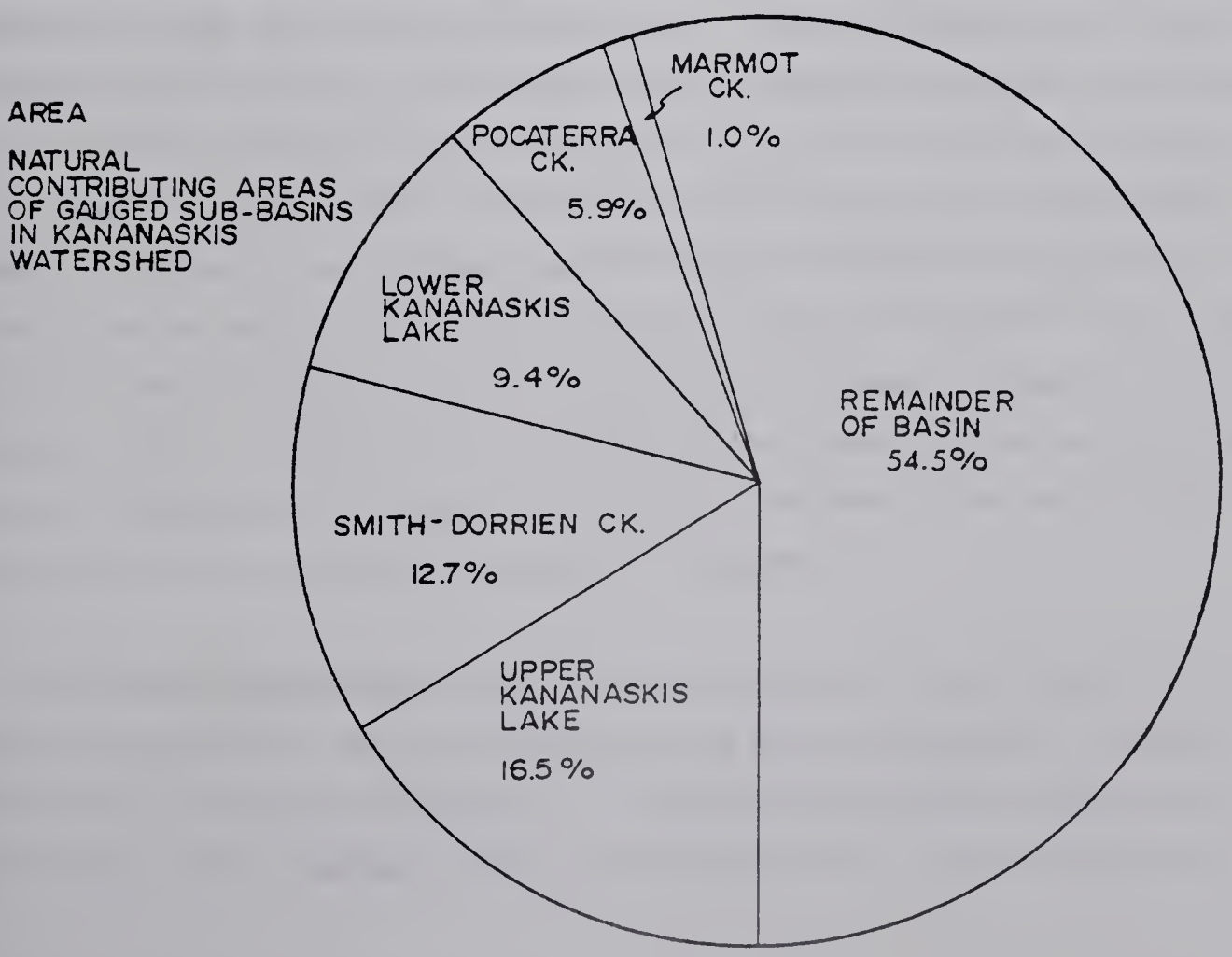
Measurements of precipitation and evapotranspiration for Kananaskis E.S.C. provide more precise information. Mean annual precipitation is slightly over 625 mm (25.0 in.), while evapotranspiration estimates derived from Class A pan readings and energy budget calculations average 500 mm (20.0 in.), thus leaving about 125 mm (5.0 in.) available for runoff. Many investigators have assumed that potential evapotranspiration is equal to lake evaporation as determined from National Weather Service Class A pan records. This is not theoretically correct because the albedo of vegetated areas and soils ranges as high as 45 percent. As a result, potential evapotranspiration should be somewhat less than free water surface evaporation. Errors in estimating free water evapotranspiration from pan records are such, however, as to make an adjustment for potential evapotranspiration of questionable value (Viessman et. al., 1977).

The patterns described above reveal some very striking differences, on an intra-regional basis, about the ability of a basin to generate runoff. From the map it is obvious that the higher bare rock and rocky alpine areas contribute the greatest amounts of runoff in proportion to the precipitation received. Some areas of the District, including some vegetated areas consistently generate more runoff on average than other areas, and from a watershed management viewpoint, it is these high runoff areas that may have a potential for water yield or regime management. Where stream gauges and flow records are available, it is possible to examine the mean and extreme runoff events for each drainage unit in detail. Figure 4.2c illustrates the relationship between individual gauged drainage units, by area, and the average annual runoff from each gauged unit as a percentage of the total annual runoff from the Kananaskis District.

The most efficient sub-basin drainage unit, in terms of its 32 percent runoff - 16.5 percent area ratio, is that area above Kananaskis Lake. This high elevation area, dominated by steep slopes and alpine rocklands receives considerable precipitation along the Continental Divide, especially near the Mangin Glacier in the south, and the Haig Glacier in the north. Talus and colluvial materials dominate the middle and lower slopes, acting as detention storage for runoff from bare rock areas above. Since retention storage is poor in these coarse materials, vegetation is generally absent, thus losses due to evapotranspiration are low. Some spruce-pine associations can be found on the south shore of the main lake and in the Upper Kananaskis River valley, but these areas receive far less precipitation than the upper slope areas, and subsequently generate proportionately less runoff.

Figure 4.2c PERCENT AVERAGE NATURAL ANNUAL RUNOFF FROM KANANASKIS DISTRICT





The Smith-Dorien sub-basin drainage unit, while smaller in area than the Upper Kananaskis drainage unit, contributes on average over14 percent of the natural runoff of the entire Kananaskis basin. The Smith-Dorien valley is narrow, from 3 km (2.0 mi. approx.) wide in the vicinity of Mud Lake, to less than 1 km (0.6 mi.) wide for much of its 16 km (10.0 mi. approx.) length. Glacial till and glacial-fluvial materials can be found immediately along the main stream channel and in some of the larger tributaries. These deposits provide a significant amount of detention storage for runoff from upper slopes, however retention storage is not adequate in the generally shallow alluvial materials which overlie these deposits, therefore forest cover is discontinuous. In the lower slope areas where till predominates, such as in the vicinity of Mud Lake, retention storage is more than adequate for forest cover use. As a result, some of the best mature spruce timber stands have been found in this area and although much of this has been cut out, some stands still remain. Since storage capacities are high and evapotranspiration losses are high, about 375 mm (15.0 in.), runoff is generally low compared to the upper sub-alpine areas. Here colluvium and talus material are extensive, providing large detention storage capacities due to coarse textural characteristics, but low retention storage and therefore high runoff. The bare rock areas of the Kananaskis Range to the east, and along the Continental Divide to the west, receive large amounts of precipitation, from 1275 mm (50.0 in. approx.) near Fortress Mountain to 1525 mm (60.0 in. approx.) near Mt. Sir Douglas. Here, local runoff is high since temperatures are low and soil and vegetation are generally thin or absent, thus evapotranspiration is less than 125 mm (5.0 in. approx.).

The Lower Kananaskis Lake sub-basin drainage unit presents a remarkable contrast in runoff variations when compared to the two previously mentioned sub-basins. Smaller in area than either of the others, this drainage unit accounts for less than 6 percent of

the average annual runoff from the entire Kananaskis District. This is due to the combined effects of lower relative amounts of precipitation, lower average elevation, and an extensive vegetative cover of immature lodgepole pine mixed with spruce and sub-alpine fir. These last factors result in high rates of evapotranspiration in the valley bottom, of approximately 375 mm (15.0 in. approx.) and runoff less than 250 mm (10.0 in. approx.). Since average total runoff from this drainage unit is 330 mm (13.2 in.), the runoff from bare rock and slope areas, particularly the west slope of the Elk Range, north slope of Mount Fox and east slope of Mount Indefatigable, must be sufficiently high to compensate for the large low-runoff valley bottom area. Accordingly values depicted on the runoff map show that small high elevation bare rock areas could experience runoff up to 890 mm (35 in.) and still be consistent with known and estimated precipitation for these areas.

The Pocaterra Creek sub-basin drainage unit is unique in that, although smaller in size than the Lower Kananaskis sub-basin, it contributes virtually the same 5.9 percent amount of runoff on average. This is largely due to the combination of higher elevation, higher surface-slope area, higher relative amounts of precipitation, and higher proportion of area consisting of bare rock and coarse textured talus and colluvial materials. The Elbow Pass and the Highwood Pass areas receive up to 760 mm (30.0 in.) and 890 mm (35.0 in.) of precipitation respectively, and the surrounding slopes receive considerably more. The coarse talus and colluvial materials which make up the largest proportion of slope would experience high relative rates of runoff, over 760 mm (30.0 in.) in the Highwood Pass and slightly lower in the Elbow Pass vicinity and along the west slope of the Opal Range. Runoff extremes in this sub-basin vary from over 890 mm (35.0 in.) for bare rock areas on the east slope of the Elk Range, to less than 250 mm (less than 10.0 in.) in the till areas of the valley bottom. These values are consistent with known precipitation and snow course record values, and correlate well with vegetative

cover variations.

Much of the best information on runoff comes from Marmot Creek, and although it is too small to be thought of as a sub-basin, many of the patterns and relationships established here can be extended in a modified form to the rest of the District. The precipitation and snow course information is well documented (Storr and Ferguson, 1972) as is the effects of physical variables including vegetation on snow pack and snowmelt runoff (Golding, 1970, 1974). Evapotranspiration losses have been measured and estimated (Storr, 1968, 1974), and the streamflow record is complete and comprehensive. The relationship between precipitation, evapotranspiration and runoff has been more closely developed (Storr, 1977), and the use of supplemental information concerning the interaction of physical variables on these hydrologic parameters has already been demonstrated (Idaho Water Resources Board, 1969). The variations in runoff described above have been developed from the interaction of proven scientific relationships with theoretical considerations for those variables for which no quantitative information is available. As a result, Marmot Creek relationships have been expanded to assist in the derivation of runoff patterns for the rest of the District. While the runoff values are quantitatively precise, the spatial variability is much less so, dependent as it is on theory and recognition of various physical patterns. While even the validity of these theories may be questioned, they do offer by far the best explanation of the spatial variability of runoff and in doing so provide a wealth of detailed intra-regional information that would have been otherwise unobtainable.

4.2.3 Total Runoff: Normal and Extreme Conditions

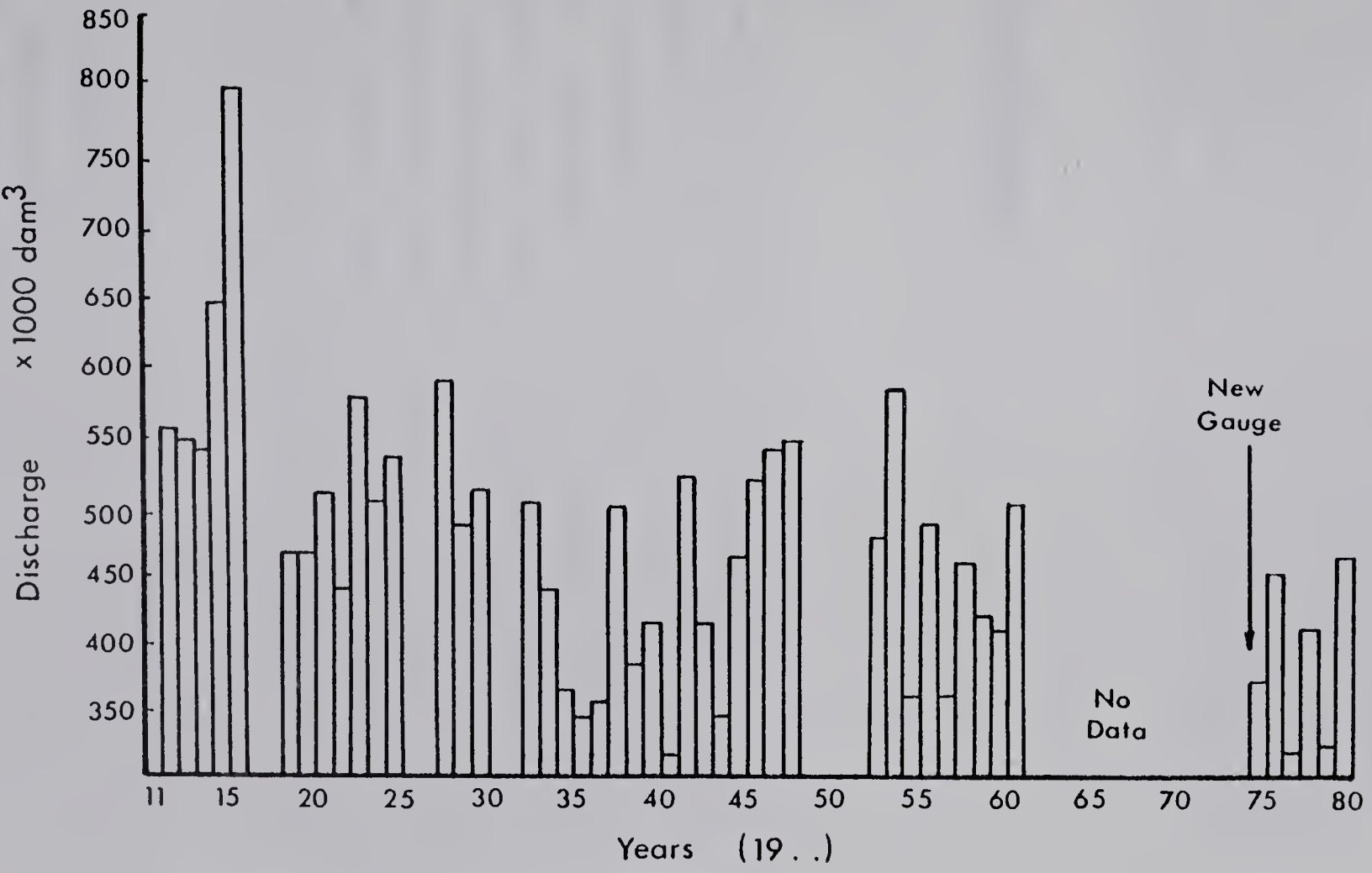
The annual mean and extreme variations in total runoff reflect changes in the physical water supply patterns as influenced by man

and nature. The development of increased storage at Upper and Lower Kananaskis Lakes, and the creation of Barrier Reservoir has, in part, effectively reduced the mean runoff from the entire watershed. For example, prior to 1933, the annual mean runoff of the entire Kananaskis watershed was 547,670 dam^3 (444,000 Ac-ft.). During this pre-development period, total annual runoff extremes ranged from a low of 441,590 dam^3 (359,000 Ac-ft.) to a high of 799,300 dam^3 (648,000 Ac-ft.) (Environment Canada, 1979).

The post-development period after 1933 is marked by a general decline in the average and extreme runoff values due, in part, to an associated lower yield climatic period, and to man's storage developments. Increases in water storage, combined with small scale diversions which transfer water from the Upper Smith-Dorien valley into the neighbouring Spray watershed have reduced the annual runoff to 447,760 dam^3 (363,000 Ac-ft.). Similarly, the extreme minimum runoff declined to 329,340 dam^3 (267,000 Ac-ft.), while the extreme maximum declined to 576,040 dam^3 (467,000 Ac-ft.). Figure 4.2d depicts the annual total discharge for the period of record for the Kananaskis River at the main gauge, located downstream from Barrier Reservoir.

Although man's diversions and storage works have combined to significantly influence the variations in total runoff from one year to the next, nature has ultimately controlled the degree to which the variations have occurred. For example, the years of 1915-1916 experienced high runoff values which have not been approached since. The 1916 flow of 799,300 dam^3 (649,000 Ac-ft.) represents a water yield of 851.2 mm (33.5 in.), a 64 percent increase over the long term average of 517.5 mm (20.4 in.). An explanation for this extreme may be that precipitation amounts in the higher back range areas were extraordinarily high. However, precipitation records for the region are not available to serve as a check. An interesting observation is that records for the Bow River at Lake Louise and Banff show runoff values per unit area far lower than the Kananaskis value, thus placing the published extreme value in a nebulous position.

Figure 4.2d Total Annual Discharge For Kananaskis River Below Barrier Reservoir



Source: Environment Canada, 1975-1980.

Neill et al (1970) has suggested that regional climatic trends can be linked with the relatively low annual runoff totals in the 1930s and some years of the 1940s. Precipitation records for Banff and Calgary, combined with streamflow records of the Bow River during these years, show declines in precipitation that are mirrored by lower runoff values. Precipitation records for Kananaskis E.S.C. show that total precipitation was well below average in both 1940 and 1941 by approximately 25 percent, therefore nature merely accentuated the low runoff values already influenced by the increases in reservoir storage.

4.3 STREAMFLOW CHARACTERISTICS

4.3.1 Natural Flow

While a discussion of generalized runoff variations relies on streamflow information to define workable limits, there is little explanation of the variations in streamflow. It is not enough to just give statistics detailing streamflow patterns since there are definite variations in these patterns related to various management objectives. The following discussion is an examination of the data in order to demonstrate the spatial variations in streamflow conditions. Also a comparison of present streamflow variations with past conditions will illustrate some of the changing management orientations which have affected the hydrology of the Kananaskis District.

The natural flow characteristics of most of the smaller tributary streams have remained the same throughout the period of reservoir development. Major streams such as Evans-Thomas, Ribbon, Marmot, Wasootch, Pocaterra, Boulton and King Creeks, all respond like typical mountain streams; experiencing a high spring flow, due to snowmelt, that rapidly declines through the summer-fall period to low winter base-flow conditions. At higher elevations many creeks

may be dry for much of the year particularly in dry years. Such occurences are common in Marmot Creek where thin, coarse talus materials along the headwalls of Mt. Allan readily lose their moisture, resulting in intermittent summer flow. During the winter period most of the smaller creeks freeze over, aiding in the decline in winter flow in the main Kananaskis River. Flow variations within seasons are usually smaller in magnitude than flow variations between seasons for a given year, for any of the smaller tributary streams. However, flow records for most of these streams are either short, discontinuous or entirely absent so very little quantitative information is available. Observations by the author and by numerous individuals who live and work in the District, have verified both the seasonal and annual variations in streamflow discussed above.

The flow record for the main Kananaskis River is more complete, with approximately 50 years of published data available. Natural flow records are available for the period 1911 to 1932, at which time construction of the Upper Kananaskis Lake dam began and regulation of part of the watershed followed. The natural seasonal flow variations are quite apparent from Figure 4.3a. The most striking feature of this flow diagram is the steep rising limb in May attributed to snowmelt runoff. Streamflow reached its peak in June and then began to decline in July, continuing to decline less rapidly during the fall period, eventually reaching a low winter baseflow level. Monthly mean discharges for the January to March period were remarkably constant, averaging 3.5 cms (125 cfs) with a standard deviation of 0.6 cms (23 cfs). During the month of April, mean streamflow increased to 4.6 cms (162 cfs) and the range in streamflow also increased. A sharp increase in mean streamflow occurs in May; however, the standard deviation about this mean monthly flow of 53.8 cms (1900 cfs) has an historical flow range of between 88.9 cms (3141 cfs) and 24.9 cms (879 cfs). As the monthly mean streamflow values decline, so also do the extremes and

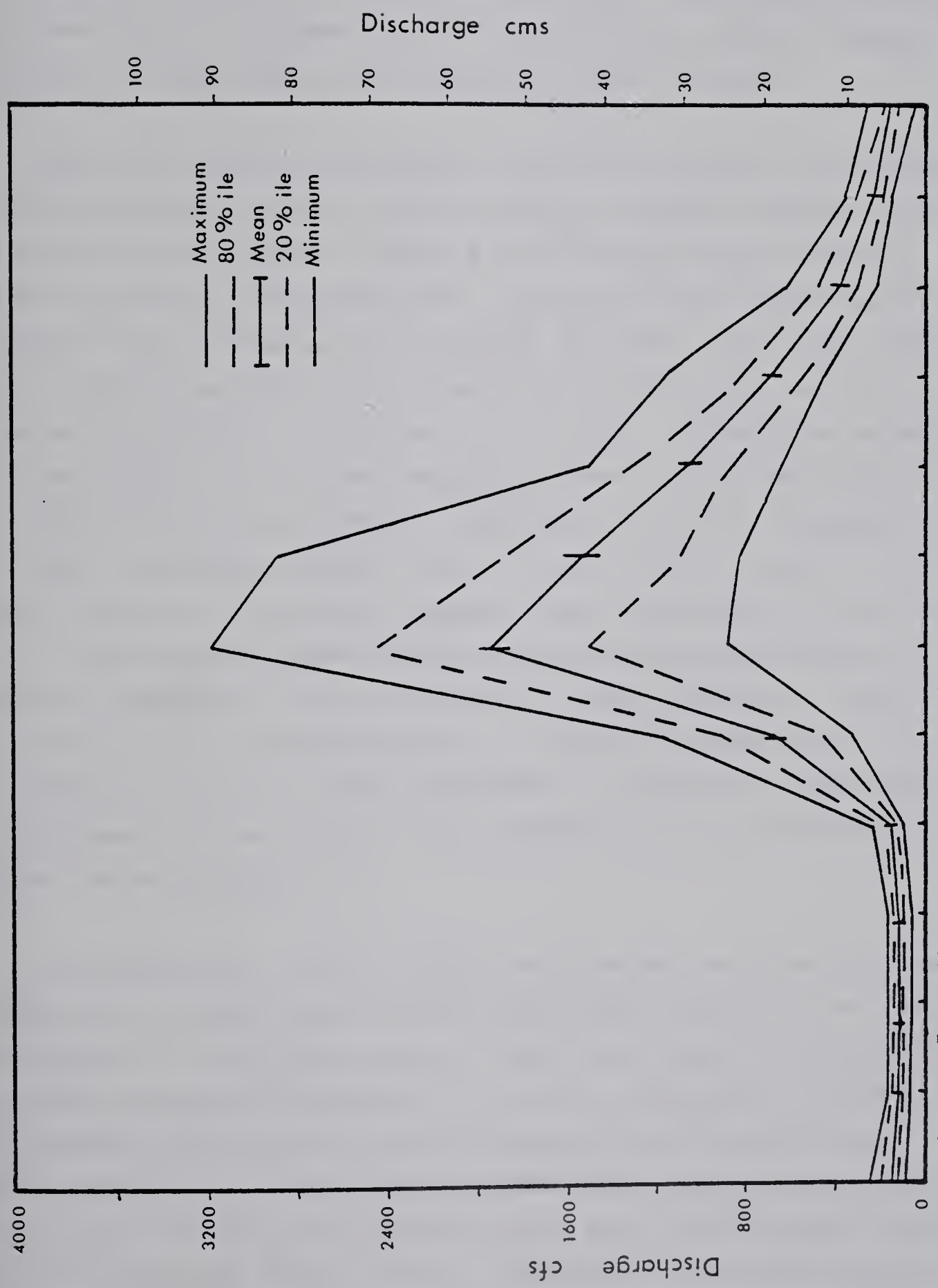


Figure 4.3a Discharge Summary 1911 - 1932, Kananaskis River

the standard deviation about the monthly mean. For example, the monthly mean flow for November was 6.8 cms (239 cfs) and the standard deviation of flows about this mean was 1.6 cms (57 cfs).

While the monthly flow summary depicted in Figure 4.3a indicates a marked seasonal contrast, there is also a distinct pattern in the duration of flow volumes. Figure 4.3b illustrates flow duration curves for natural flow conditions, controlled flow conditions and combined flow conditions for the period 1911-1962. The graph shows that a monthly mean flow of at least 9.2 cms (325 cfs) could be expected approximately 50 percent of the time. Streamflows exceeding 28.3 cms (1000 cfs) occurred about 20 percent of the time during the 1911-1932 period of record. Conversely, at least 35 percent of the time, streamflow was less than 5.7 cms (200 cfs); and for at least 5 percent of the time, streamflow was less than 2.83 cms (100 cfs). The contrast between natural flow and controlled flow is apparent from Figure 4.3b and details of these differences will be dealt with in the following section. The flow duration curve of the complete period of record (1911-1962) is included to show how the extremes of flow are not readily apparent due to the change in regime characteristics.

In combination, the 1911-1932 flow duration curve and discharge summary for the same period indicate sustained periods of low flow, particularly in the winter period. While this regime is indicative of typical mountain streamflows, it is not a seasonally equitable flow pattern since much of the peak spring flow is flashy flow. A more equitable streamflow regime would include higher, sustained flows during the fall-winter period and a lower, more equally distributed flow over the summer period. The benefits of a more equitable streamflow regime would include reduced flooding and erosion during the high peak flow period, improved water quality due to increased aeration characteristics, improved habitat conditions for fish and wildlife, improved recreational environment due to more consistent flows, and improved water supply characteristics for both

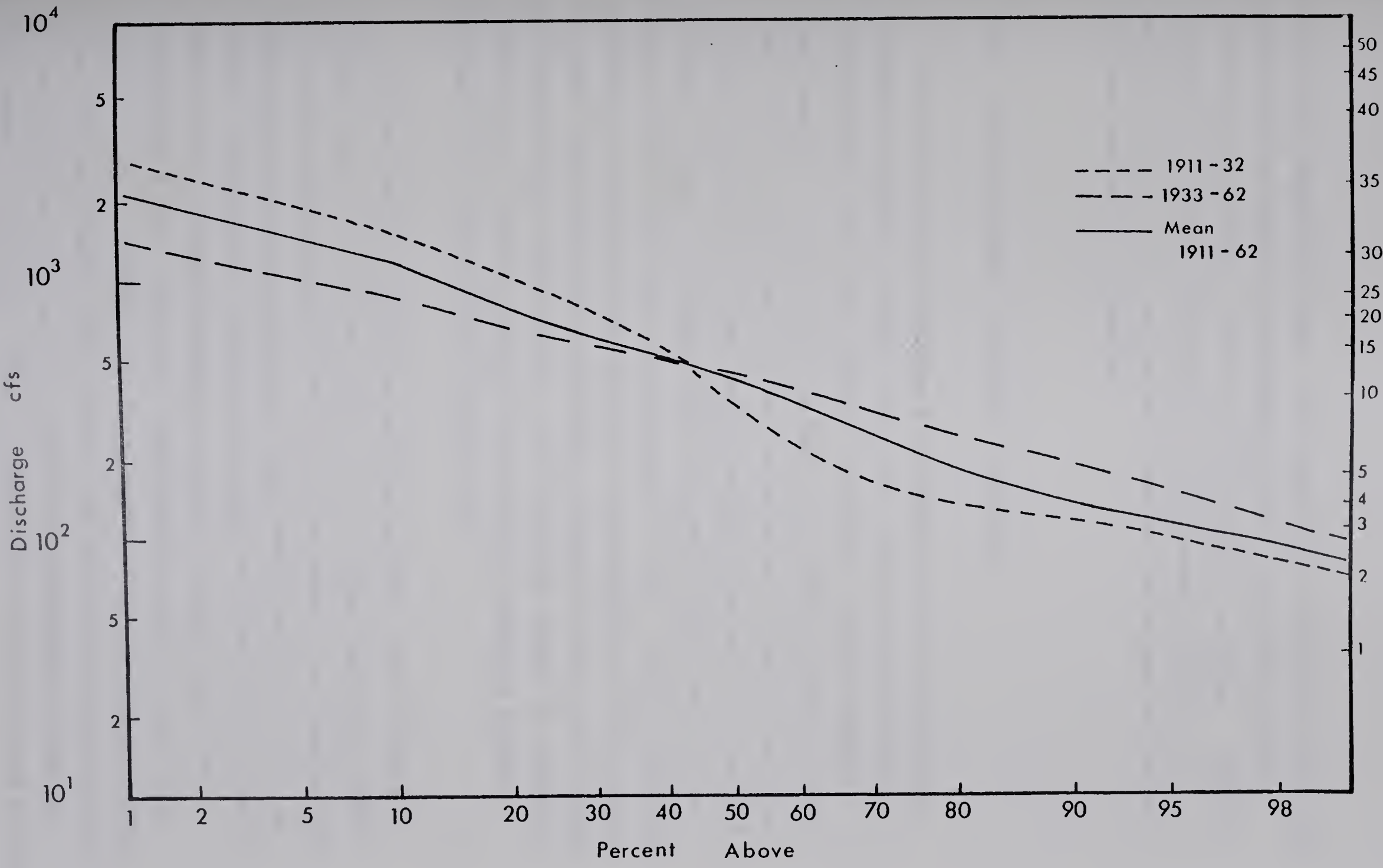


Figure 4.3b Monthly Duration Curves, Kananaskis River

on-site and downstream users. The suggestion that natural flow conditions can be improved environmentally for the maximum benefit of many users (Laycock, 1973) is not yet widely accepted. However, examples of regime modification in the Kananaskis District are available and the next section will examine the nature and extent of these changes on streamflow.

4.3.2 Post-Development Streamflow Conditions

With the initial development of storage in 1933 followed by subsequent increases in later years, the regime characteristics of the Kananaskis River and a number of tributary streams changed significantly. In the first few years after 1933, reservoir operations did not significantly alter the seasonal streamflow patterns, although monthly mean flows during the high flow month of June did decrease a little. Not until 1939 did monthly mean flow decline below 28.3 cms (1000 cfs) for the month of June. As each additional increase in storage was developed for the production of hydro power, the peak flows during June decreased, allowing for more flow during the low-flow fall winter period. The resultant change in regime is reflected by a striking change in the monthly discharge summary for the period 1933-1962 (see Figure 4.3c).

Unlike the flow conditions depicted earlier, the 1933-1962 patterns show a much larger range in fall, winter and spring flows, and a much lower mean peak flow during the summer. For example, the monthly mean discharge during the January-March period of 10.9 cms (385 cfs) represents a three-fold increase over the 1911-1932 period. Similarly, the standard deviation about the monthly mean flows increased to 5.7 cms (202 cfs), approximately double the previous situation. It is important to note however that the minimum extreme values for the November-April period, and the maximum extreme values for the high flow June and July period are predominantly from the early years of 1933-1938. This is supported by Table 4.2b and by the

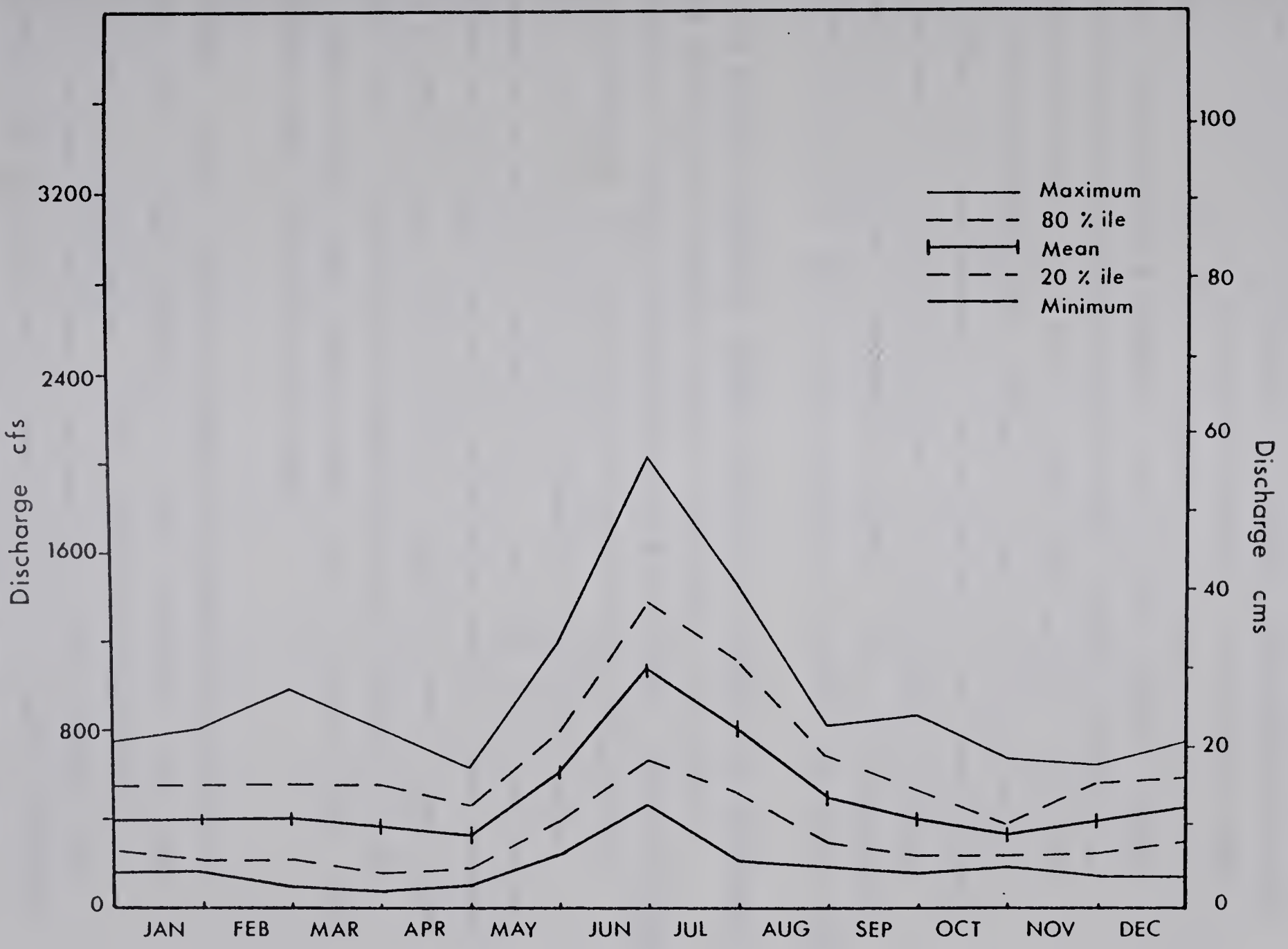


Figure 4.3 c Regulated Flow Summary – Kananaskis River 1933 - 62



values depicted in Figure 4.3c. The 20th percentile of discharge for the 1933-1962 period is consistently higher than any extreme maximum flow value in the months of December through March for the 1911-1932 period. Also the extreme maximum flow values for June and July for the 1933-1962 period, more closely approximate the monthly mean streamflow values of the 1911-1932 period. Perhaps the most significant alteration of natural regime conditions is apparent from comparisons of the summer-fall periods. The 1933-1962 July through September streamflow results show that monthly mean flows have been reduced to below the natural extreme minimum flow values for the 1911-1932 period. For the purpose of better comparing the changes in streamflow regime, a Table of descriptive measures for each of the two time periods is included (see Table 4.3a).

The monthly discharge summary depicted in Figure 4.3c indicated a less distinctive seasonal contrast than before, and this is evidenced by a change in the duration of flow volumes. With reference to the previously discussed monthly duration curves presented in Figure 4.3b, it is apparent that extreme flow values are muted. For example, streamflows exceeding 28.3 cms (1000 cfs) occurred only 5 percent of the time, and as was noted above most of these extremes could be found between 1933 and 1938. Similarly, monthly mean flows of less than 5.7 cms (200 cfs) comprised about 10 percent of the time, while monthly mean flows of less than 2.83 cms (100 cfs) would occur only about 1 percent of the time.

Under natural streamflow conditions, discharges greater than 9.2 cms (325 cfs) were available at least 50 percent of the time. After reservoir development, 9.2 cms (325 cfs) was available at least 70 percent of the time. The results of this analysis show that regime modification was achieved during the reservoir development period, such that peak flows have been reduced and a more equitable seasonal flow is made available.

Table 4.3a

Descriptive Measures of Average Daily Streamflow During Natural (1911 - 1932) and Post-Development (1933 - 1962) Periods for the Kananaskis River

MONTH	PERIOD	YEARS	MIN.	MAX.	MEAN	STD. DEVIATION
January	1911-1932	18	2.24	4.70	3.58	0.69
	1933-1962	26	4.56	22.51	11.01	4.81
February	1911-1932	18	1.99	4.76	3.45	0.69
	1933-1962	27	2.71	27.64	11.18	6.49
March	1911-1932	18	1.99	4.68	3.55	0.59
	1933-1962	26	2.07	22.18	10.18	5.66
April	1911-1932	20	3.02	6.44	4.54	1.13
	1933-1962	28	2.58	17.28	8.87	4.25
May	1911-1932	21	9.18	32.48	19.00	6.89
	1933-1962	27	6.41	33.32	16.76	7.58
June	1911-1932	21	24.61	87.92	53.55	17.33
	1933-1962	28	12.68	56.56	29.96	11.33
July	1911-1932	21	23.16	79.80	42.22	13.22
	1933-1962	28	5.68	40.60	22.30	9.25
August	1911-1932	21	18.09	41.44	29.23	6.68
	1933-1962	29	5.09	22.65	13.66	5.02
September	1911-1932	22	12.77	31.92	19.00	5.19
	1933-1962	29	4.12	24.13	11.03	4.94
October	1911-1932	22	6.22	17.16	10.84	2.97
	1933-1962	28	5.04	18.54	9.02	3.25
November	1911-1932	20	4.40	9.94	6.69	1.61
	1933-1962	28	3.84	17.67	10.73	4.17
December	1911-1932	18	1.79	7.45	4.58	1.32
	1933-1962	26	3.75	10.52	12.44	4.29

Flow Gauge 05BF001

Data from: Environment Canada, 1977

All Values in cms
1 cms = 35.3 cfs

The pattern of streamflow regime modification is supported by streamflow records in the upstream part of the basin as well. The recording gauge (05BF003) located on the Kananaskis River above its junction with Pocaterra Creek provides the best information on the alpine zone of the District. However, during its 1931-1955 period of operation, there are numerous data gaps making conclusive statements about changing regime patterns very difficult. There are a number of similarities between the two flow gauge data records, particularly the timing of changes in streamflow regime. For example, up to 1938, the data show the characteristic pattern of increasing streamflow in May, reaching a peak in June and July, and then declining to a fall-winter-spring low flow (see Figure 4.3d). The seasonal flow distribution of 1933 is indicative of the general patterns of streamflow up to and including 1938. After 1938 the flow distribution is altered due to changing operational strategies on behalf of TransAlta Utilities and the monthly mean flows are reduced during the highflow June and July period, resulting in increased monthly mean flow during the fall-winter and spring. The pattern to the regime presented by the downstream gauge, and the plotted information of the monthly mean for the entire period of record (1931-1955) reflects this similarity. By virtue of its downstream position and its larger area, 938 sq. km. (362 sq. mi.) as opposed to 363 sq. km. (140 sq. mi.), gauge no. 05BF001 reports a larger peak flow during the summer period due to the input of numerous uncontrolled streams below the upstream gauge. Otherwise, the changes in streamflow regime during the reservoir development period are similar in most respects for both gauge locations.

The reason for stressing the similarity in regime changes over time is important for several reasons. It is not necessarily true that the gauge furthest downstream will reflect the regime characteristics of streamflow in the upper part of the basin. Also this is particularly true if some degree of river control is



1933 Pattern Typical of pre-1938 Operation



1931-1955 Monthly Mean Streamflow Illustrating Effects of a Change in Operational Strategy

Figure 4.3d Seasonal Variation of Monthly Mean Streamflow for the Kananaskis River above Pocaterra Ck., Gauge No. 05BF003.

effected between the two gauges. Therefore, if changes in the operational strategy of the upstream reservoirs was to differ from that of the downstream portions of the basin, then the downstream flow gauge might not in fact reveal the differences in streamflow regime. It is for these reasons that a detailed look at contemporary streamflow patterns of the 1970s is necessary, and the following discussion will highlight the variations in upstream-downstream regime characteristics.

4.3.3 Contemporary Streamflow Patterns

The strategy of operation of the Bow River basin reservoirs has changed with time, and these changes are reflected in changes in streamflow patterns. During the reservoir development period hydroelectricity provided the bulk of the generated power used in Alberta. In the early 1960s the expansion of thermal generating facilities took place and the proportion of the total energy demand supplied by hydro-power decreased rapidly (Calgary Power Ltd., 1973). The last decade has seen the hydro storage operation change again, from that of complementing thermal power generation on a seasonal basis, to that of providing peak load power.

The changes in streamflow regime due to changing operational strategies are best illustrated by comparing the upstream and downstream flow records of the Kananaskis River. In 1974, new flow gauges were installed on the Kananaskis River above Pocaterra Creek (gauge 05BF003) and below Barrier Reservoir (gauge 05BF025). Since drainage areas have changed only slightly for each gauge, the comparisons of historical and contemporary flow patterns between gauges should be valid.

An examination of the monthly mean flow values of the downstream gauge below Barrier Reservoir (gauge 05BF025) reveals how striking the changes are when compared to the post-development conditions presented in Figure 4.3c. The seasonal regime patterns of the most recent 1975 to 1979 flow years for the downstream gauge are illustrated in Figure 4.3e. Streamflow has reached its highest peak during the November to March period as shown in this figure. During June, a high average flow is maintained due to high runoff-high precipitation characteristics; however, the mean is approximately one-half the 1933-1962 value. When the contemporary patterns are compared to the natural patterns, (see Figure 4.3a), the changes are even more dramatic. The present monthly mean June flow is approximately one-quarter the size of the natural flow, while the present winter flows are approximately four times as large as the natural flows. On the whole, this suggests that a more equitable flow distribution, in terms of each month having approximately an equal flow, has been achieved. There are, however, variations within the monthly flow patterns that show a very highly controlled regimen. In any month of the year, streamflow emanating from Barrier Reservoir might vary as much as 14.2 cms (500 cfs) within a 24-hour period. For example, on July 1, 1976, mean daily flow measured 18.4 cms (650 cfs), but on July 2, 1976, mean daily flow measured 2.1 cms (74 cfs). There are many examples of this large daily fluctuation although the summer months appear to have the majority of them. In figure 4.3f the variations on a daily basis that occurred in the month of July, 1977, are illustrated. This flow pattern reflects the operational strategy of employing hydro-power to supplement the peak power requirements of mid-week consumers, and conserving storage during the weekends (Calgary Power Ltd., pers. comm., 1979). The desirability of the effect which this operational strategy has on streamflow regime can be evaluated with a better definition of regional objectives and in Chapter 5 closer examination of this question will be made.

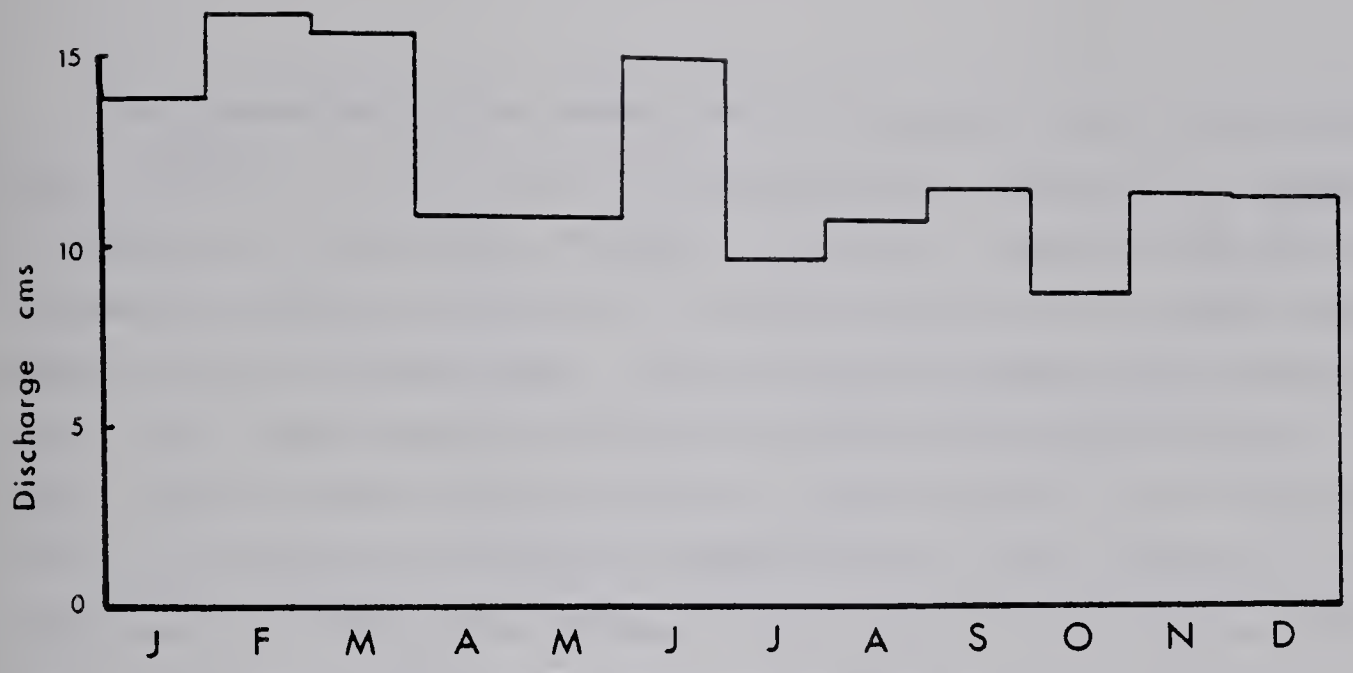


Figure 4.3e Seasonal Streamflow Patterns of the Kananaskis River Below Barrier Reservoir, 1975 - 1979.

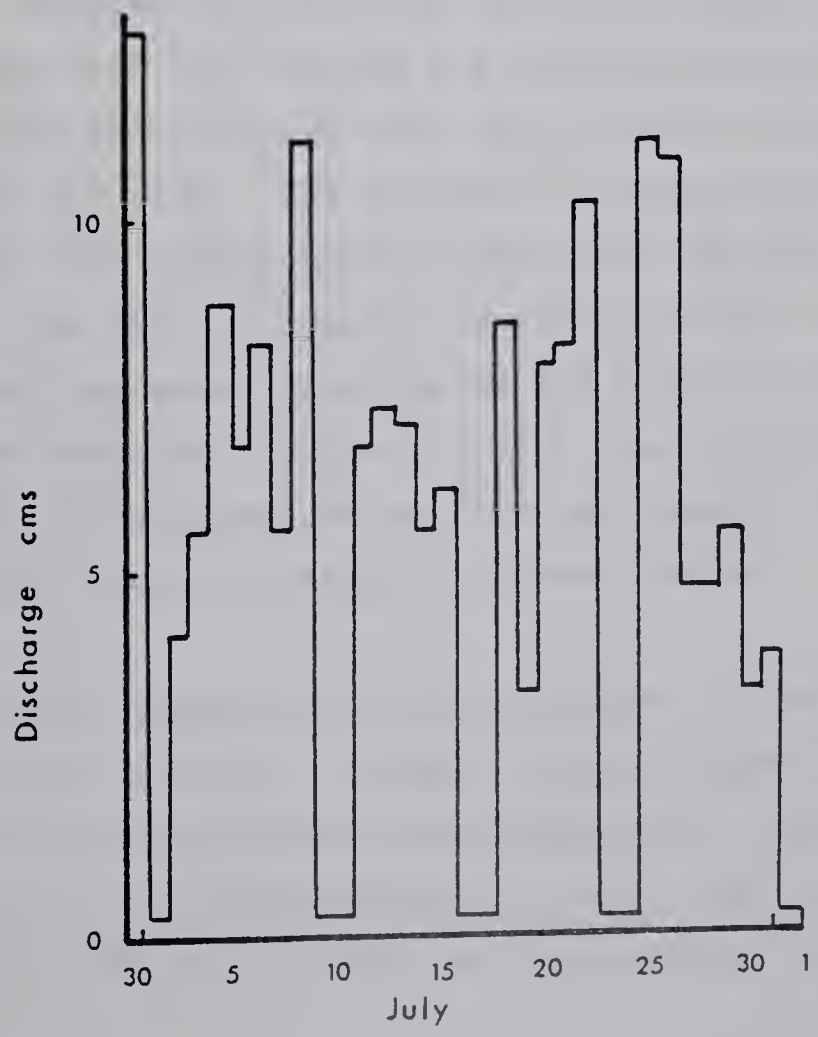


Figure 4.3f Daily Streamflow Variations of the Kananaskis River Below Barrier Reservoir, July 1977

When compared to the downstream flow gauge values, the upstream gauge (05BF003) located above Pocaterra Creek, indicates a regime pattern that is extremely variable in nature. Figure 4.3g illustrates the seasonal regime patterns of the most recent 1975 to 1979 flow years for the upstream gauge. Even though the number of years of data is not large, and the variation about the monthly mean is large, the important aspect to note is the relative size of the flow values, particularly during the summer period, when compared to historical and downstream values. Historically, the drainage area above this gauge supplies on average, approximately 60 percent of the streamflow in the Kananaskis River (see section 4.2.2). The regime characteristics measured by this gauge during the post-development period of 1933 to 1955 illustrates a modified seasonal flow which is quite dissimilar to the present flow conditions (see Figure 4.3d). Whereas the June and July flow values average approximately 13.7 cms (485 cfs) during the reservoir development period, recent statistics show average June and July flow values of approximately 1.6 cms (55 cfs). The contrast in present day conditions between the two flow gauges becomes even more apparent when a detailed look at the daily discharge records for 1977 reveals that July, August and September experienced 3-4 days each where measurable streamflow averaged 0.03 cms (1 cfs) (see Figure 4.3h). On other occasions streamflows varied from the leakage value to as much as 17.1 cms (606 cfs) within a 24 hour period.

The data above suggest that under present operating conditions, flow in the stretch of river between Pocaterra Creek and Barrier Reservoir has on some occasions been effectively reduced by well over 50 percent. In a particularly dry year, when runoff from the upper sections of the basin supply an even greater proportion of

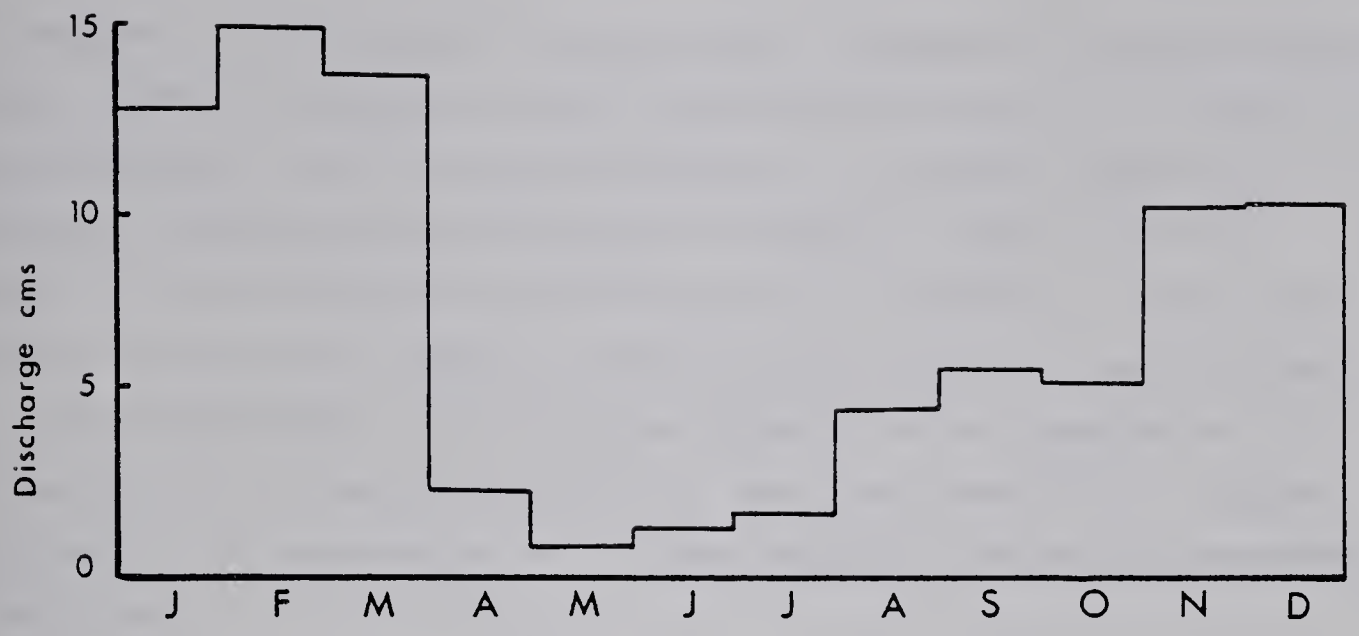


Figure 4.3g Seasonal Streamflow Patterns of Kananaskis River Above Pocaterra Creek, 1975 - 1979, Gauge No. 05BF003.

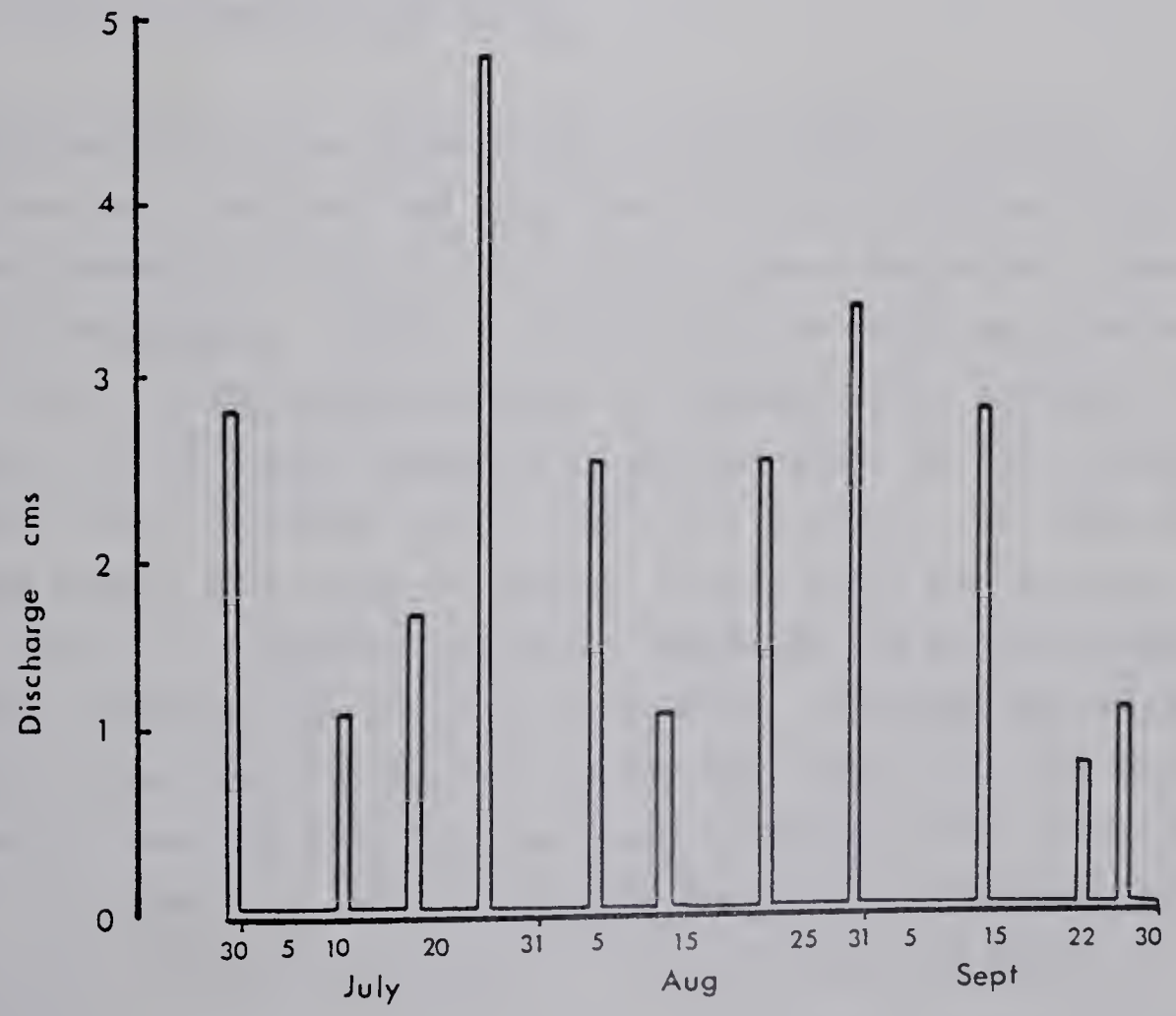


Figure 4.3h Daily Streamflow Variations of the Kananaskis River Above Pocaterra Creek, July - Sept, 1977.

streamflow, the effective flow in a major segment of the Kananaskis River, might be reduced to such low values that use of the river by recreationists, fish and wildlife might be seriously impaired. Personal observations by the author during the summer of 1978 attest to the extreme daily variability of streamflow, however the effects of these low flows on existing and potential users has not yet been determined. The following chapter is an examination of the nature of streamflow variability and the potential for regime improvement in combination with other potential watershed management objectives.

4.4 SURFACE STORAGE IN LAKES AND RESERVOIRS

4.4.1 Pre-Development Conditions

Information on the lakes prior to development is scarce. Lake level data were obtained and published for brief periods during 1932 on Upper Kananaskis Lake, and for 1933 on Lower Kananaskis Lake prior to development. However the data are so brief as to be of very little use in establishing average or seasonal water levels. For example, in 1932, Upper Kananaskis Lake was shown to have a mean December level of 1682 m. a.s.l. (5520 ft. a.s.l.). In 1933 the same lake had a mean June level of 1680 m. a.s.l. (5513 ft. a.s.l.). This is the result of TransAlta Utilities deepening the outlet channel to allow the original lake level to be lowered. Although earthfill had been placed over the outlet, it was not until 1936 that the full supply level of that time was used (Nelson, 1965). The construction of the upper dam site during 1933 would also influence the latter's water level, although the extent of this influence is not well documented.

For Lower Kananaskis Lake, the published data for June of 1933 indicate a monthly mean level of 1657 m a.s.l. (5432 ft. a.s.l.). This corresponds to the natural level estimated by Calgary Power Ltd. (Osborn and Jackson, 1974).

Prior to the development of Barrier Reservoir, the Kananaskis River had cut a steep but narrow valley into the relatively soft shaly sandstone, of Cretaceous age, to the east of Pigeon Mountain. Construction of the reservoir in 1947 obliterated the original valley cut; however, a small portion is still visible immediately downstream of the damsite.

There is a large number of small lakes, ranging in area from a few square kilometres to less than 100 sq. m (1076 sq. ft.). The largest of these include Hidden, Three Isle, Aster, Sarrail, Maude and Lawson Lake, and all are found in glacially eroded bedrock basins near the Continental Divide. A number of small lakes, or ponds can be found along the lee slope of the Kananaskis Range in the headwaters of Galatea and Ribbon Creeks. While a few of these are located in tarns, those in valley bottoms are impounded by glacial deposits. The small ponds east of Lower Kananaskis Lake lie in groundwater controlled pro-glacial channels which are hydrologically linked with Pocaterra Creek.

In general, all lakes follow the seasonal pattern of fill during periods of high inflow (spring runoff) and decline during periods of low inflow. Tarn Lakes experience slower rates of inflow in spring due to delayed melting at higher elevations, yet retain fairly constant levels due to their bedrock basins, which reduce seepage losses. Hidden Lake is different in that its morainal impoundment allows for significant leakage and thus seasonal fluctuations. Valley lakes and ponds experience large fluctuations

in levels due to seasonal responses to inflow and outflow. Some of the smaller ponds actually are sedge belted marshes which, under prolonged dry conditions, would have little standing water. Extreme variations of the larger lakes are not readily documented before reservoir development however an appreciation of runoff and lake level variations can be deduced from post-development records.

4.4.2 Reservoir Development Period

An investigation into the hydro-electric potential of the Kananaskis Lakes was first reported as early as 1914 (Hendry, 1914). Although Upper Kananaskis Lake was considered to be too beautiful to be used for hydro-electric purposes (Hendry, 1914), the year 1933 saw the end of natural conditions. Calgary Power Co. Ltd. raised the lake level 6.1 m (20 ft. approx.) in order to provide storage for use at downstream power plants on the Bow River. This increased the lake level to 1689 m. a.s.l. (5537 ft. a.s.l.) and provided a degree of flood control, as well as regime improvement in streamflow conditions. While streamflow in the summer high-flow period was decreased slightly by this provision for storage, there still existed virtually no control of a significant amount of the spring runoff hence summer runoff was still disproportionately larger than for any other time of year.

In 1942, Calgary Power Co. Ltd., built an addition to the Upper Kananaskis lake dam, raising the storage level over 15.3 m (50 ft. approx.). Given an average maximum water level of 1703 m. a.s.l. (5583 ft. a.s.l.), the potential storage capacity of the reservoir was increased to 123,350 dam^3 (100,000 Ac-ft.) (Calgary Power Ltd., 1973). Of this total, 35,772 dam^3 (29,000 Ac.-ft.) is considered to be dead storage.

In 1947, the Barrier Reservoir was created by damming the main Kananaskis River approximately 5.8 km (3.6 mi. approx.) upstream from its confluence with the Bow River. When first constructed, its 24,670 dam^3 (20,000 Ac-ft.) of storage played an important role in hydro-electric generation; however, the development of Lower Kananaskis Lake as a reservoir in later years, has made head more valuable at this location (Calgary Power Ltd., 1973). Barrier Reservoir has an average maximum water level of 1377 m a.s.l. (4515 ft. a.s.l.) and depletion of the total available storage results in a water level fluctuation of 11 m (35 ft.).

Lower Kananaskis Lake was expanded in 1955 to provide 61,675 dam^3 (50,000 Ac-ft.) of storage. The average maximum level of the lake was increased to 1668 m a.s.l. (5469 ft. a.s.l.) from the natural level of 1657 m a.s.l. (5432 ft. a.s.l.). In order to utilize the entire volume of storage, a drawdown of 13.4 m (44 ft.) is necessary resulting in an average minimum lake level of 1655 m a.s.l. (5425 ft. a.s.l.).

Information on the natural and artificial lake levels is provided in Table 4.4a. Surface water records for the 22-year period when major development occurred, show in general, that lake level fluctuation was highly dependent on seasonal runoff variations. The post development period is in marked contrast to the early development period and this will be explored in more detail in the next section.

4.4.3 Contemporary Storage Patterns

Lake level variations in the past decade (1969-1979) are the result of an increasingly greater influence by seasonal power demands and changing operational strategies. In the early years of operation the three major lakes were filled during spring runoff, remained high during summer and fall, and were gradually drawn down through the winter. While this statement is generally true for

Table 4.4a

Natural and Artificial Lake Levels in Kananaskis District

LEVEL	UPPER KANANASKIS LAKE	LOWER KANANASKIS LAKE	BARRIER LAKE
Natural Level Metres asl	1683	1656	No Lake
Average Maximum Level Metres asl	1702	1667	1377
Average Minimum Level Metres asl	1686	1654	1366

1 METRE = 3.281 FEET

Source: Osborn and Jackson, 1974

present operations there are some deviations. Osborn and Jackson (1974) state that filling of the lakes is completed in or near July. This is only true of Barrier Reservoir, which on average reaches just below the full supply level in late July or early August. Figure 4.4a illustrates the monthly mean water levels, including storage and percent storage values, for the period of record for Barrier Reservoir. From the diagram it is clear that, on average, Barrier Reservoir is kept above the 80 percent full storage level for eight months of the year, starting in August and lasting until March. Storage is withdrawn in April leaving about 50 percent of the total volume. Drawdown continues at a rate determined by comparing current water levels with master curves of runoff, so that the lowest storage volume is reached in May. At this time, filling has begun on the upstream reservoirs at a rate determined by runoff conditions. Barrier Reservoir generally reaches 50 percent full storage in late June and by the end of July has over 70 percent of its full storage volume.

In contrast, Lower Kananaskis Lake begins filling in May due to higher amounts of runoff generated locally and from Upper Kananaskis Lake. Figure 4.4b illustrates the monthly mean water levels, including storage and percent storage values for the period of record. Filling proceeds through June into July where, on average, about 60 percent of the total storage volume is available, and the water level is about 3 m (9.8 ft. approx.) from the maximum level. By the end of August about 75 percent of the total storage is available, and at least this much is available for the period September through January. Storage withdrawal begins in February and the lowest storage level is achieved in April.

Upper Kananaskis Lake experiences water level fluctuations which are quite dissimilar in both pattern and degree from either of the other major lakes (see Figure 4.4c). Full supply level exceeding 80 percent occurs, on average, by early October, at which time drawdown begins and continues through to late February (Environment Canada,

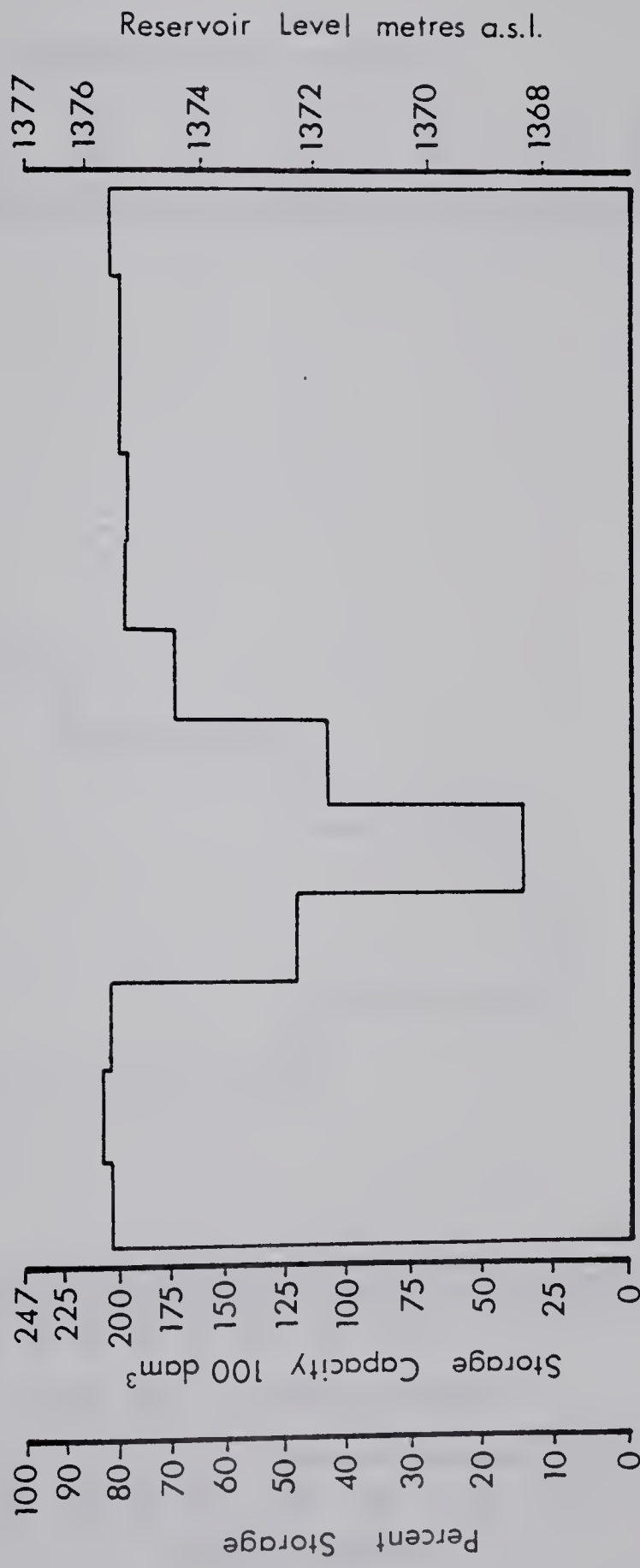


Figure 4.4a Monthly Mean Water Levels for Barrier Reservoir, 1969-1980.

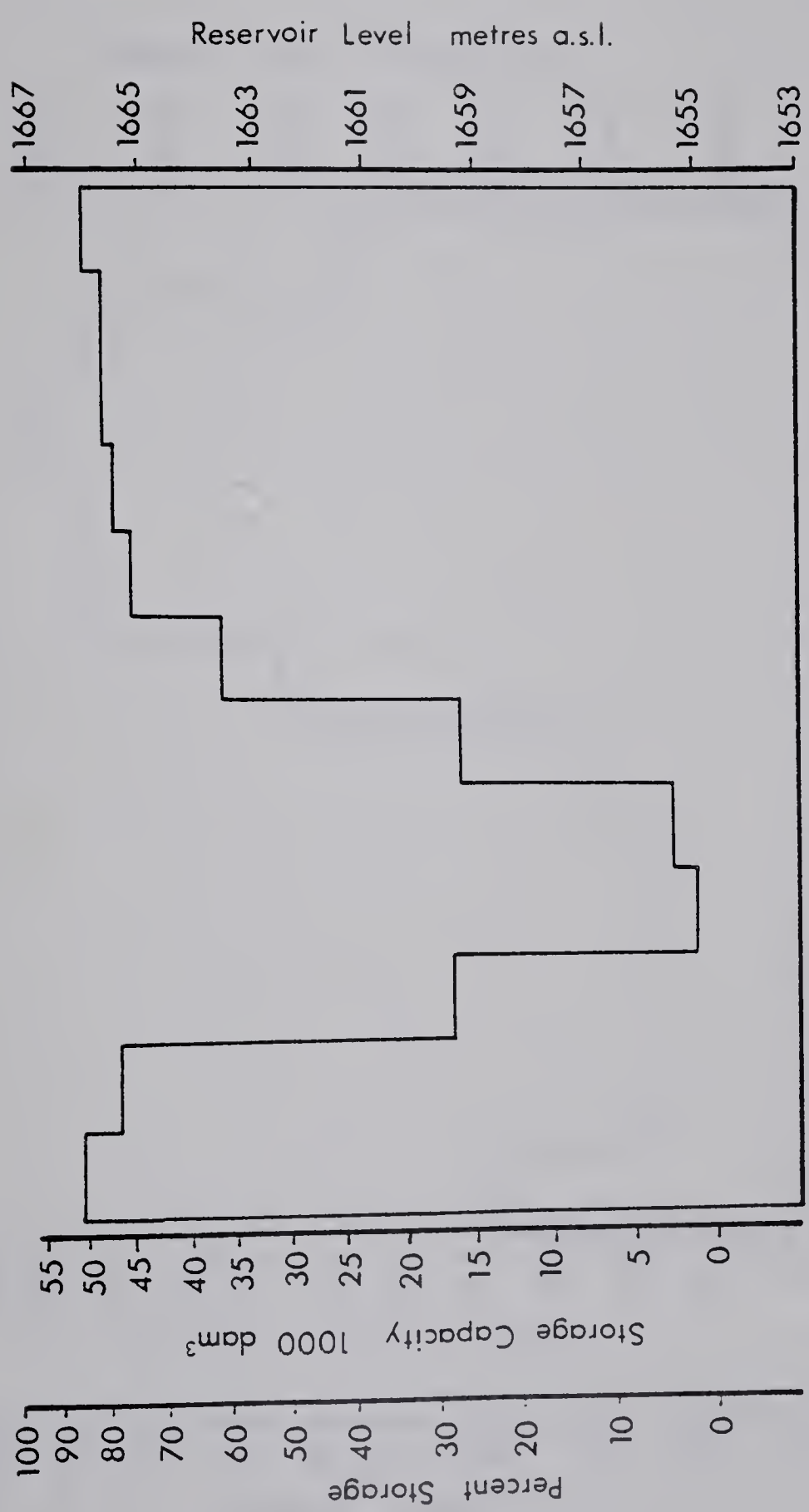


Figure 4.4b Monthly Mean Water Levels for Lower Kananaskis Lake, 1969-1980.

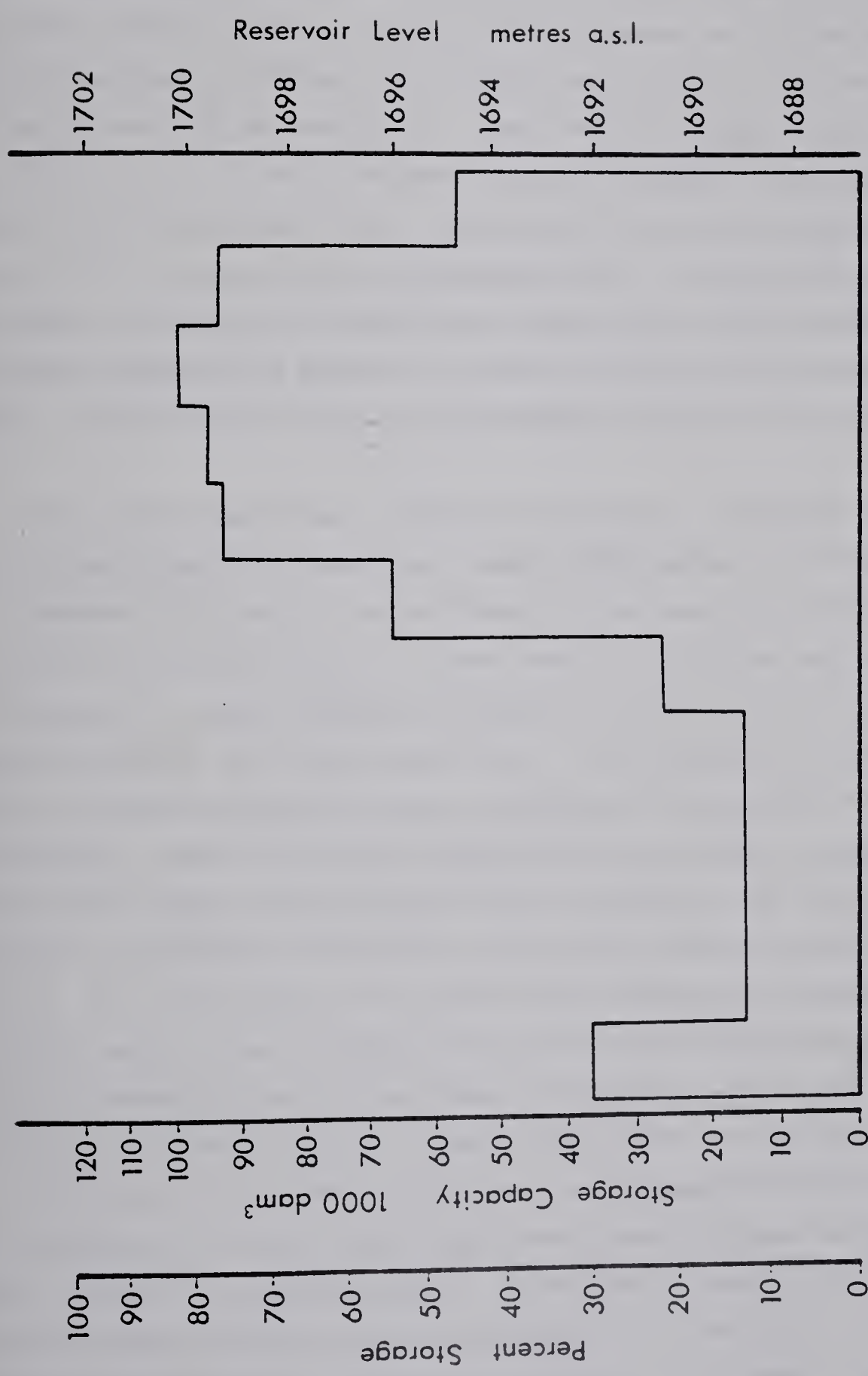


Figure 4.4c Monthly Mean Water Levels for Upper Kananaskis Lake, 1969-1980.



1980). The lowest reservoir level lasts from February through May when less than 20 percent of the total storage is available. Refilling begins in earnest in late May and by July, the lake is, on average, about 50 percent full. Lake levels at this time are about 6 m. (20 ft.) from their maximum level. By August, average storage exceeds the 75 percent level, thus lake levels are commonly within 2.5 m. (8 ft. approx.) of the maximum level. During the months of September and October intermittent power plant operations at the Interlakes generating station, produces slightly fluctuating storage levels, however the total storage usually exceeds 75 percent.

There are significant differences between the lakes in both filling and drawdown rates, and these differences are linked to the combined influence of operational procedures on runoff and streamflow characteristics. Since runoff conditions vary markedly from region to region within the District (see Section 4.2.2), natural rates of fill will also vary. Consequently drawdown begins first at Upper Kananaskis Lake, continuing from October or November to February. When the Upper lake is at a low level, drawdown begins on the Lower lake and continues until mid-April. At this time, storage is withdrawn from Barrier Reservoir from late April through to May. The end result is a system which operates in sequence, and therefore water level conditions at one time in one lake may not be directly comparable with conditions in another lake. The average conditons of drawdown and fill described above can be and commonly are varied due to a number of factors. Circumstances which may lead to variability in lake levels and river flows include uncharacteristic runoff patterns, unusual weather, variation in operational strategy of power plants (either inside or outside the District), irrigation demands on the Prairie, and special requests by farmers, construction outfits or the Minister of Environment (Osborn and Jackson, 1974). In Chapter 5, consideration will be given to possible time-conflicts in water demand and supply.

An important feature of the lake volumes which would affect other uses of the lakes, is the unnaturally low levels which occur during the summer (June through August) period. Barrier Reservoir is commonly within 3 m. (9.8 ft. approx.) of its optimum level for about half of the summer. Lower Kananaskis lake water levels vary from 8 m. (26.2 ft. approx.) in June to less than 1 m. (3.3 ft. approx.) in August, below optimum level. The variations in levels for Upper Kananaskis Lake are even more extreme. Water levels in June average 11 m. (36.1 ft. approx.) below optimum while in August levels are commonly 3 m. (9.8 ft. approx.) below optimum level.

4.5 HYDROLOGIC SUMMARY

The hydrology of the Kananaskis District has been examined from both a surface and subsurface perspective, as well as through changes in time. The subsurface characteristics of the regional water supply system are determined largely by parent material capacities, distribution, depth to bedrock, and environmental conditions. The surface hydrology is characterized by a system which has been significantly affected by the actions of man, including the creation or enlargement of lakes to be used as reservoirs, and the diversion of several small streams. The annual and seasonal patterns of runoff have changed over time in response to external demands.

In general, groundwater in the District is thoughtto occur under water table conditons, being recharged in spring and early summer by infiltration, and gradually depleted during late fall and winter. The presence of large volumes of groundwater stored in certain surficial soils, particularly the glacial tills, has been demonstrated. Some groundwater is stored in fractured shales and therefore is linked to the active groundwater reservoir, while little groundwater potential exists for the less permeable siltstones and quartzites.

An assessment of the spatial patterns of runoff was conducted utilizing innovative techniques developed and applied with success in water resource studies in the United States and elsewhere. Knowledge of generalized soil/water relationships, supported with precipitation data and estimates of evapotranspiration, enables us to obtain a representative picture of natural water supply variations within the region. The runoff map depicted is a geographical composite of the multivariate influence of vegetation, physiography and climate on the water supply patterns.

High runoff of over 90 percent of the precipitation received can be found in places along the Continental Divide and the upper ridges of the Kananaskis Range. Here precipitation amounts are the highest in the District, and runoff ranges from over 1150 mm (46 in.) up to 1500 mm (60 in.). In other areas along these major ridge systems, runoff values are also high, in the order of 875 mm (35 in.) to 1150 mm (46 in.). The intermediate valley elevations of Smith-Dorien Creek and the Upper Kananaskis River are characterized by lower runoff conditions due to several factors including distance from major ridges, deeper drift materials for greater detention storage, and more extensive vegetative cover. Thus the proportion of runoff to precipitation is approximately 50 percent or 500 mm (20 in.). The main Kananaskis Valley experiences roughly similar precipitation amounts throughout although generally lower values are evident near the Evans-Thomas Creek confluence. Since the majority of this precipitation falls as rain in the summer months, much of it is used by the vegetation present and runoff amounts vary from 40 percent or 250 mm (10 in.) to less than 20 percent or 125 mm (5 in.) of precipitation received.

Contemporary patterns of total runoff have been influenced by man's storage works, by forest regeneration and by a lower yield climatic period. Historically, total annual recorded runoff has been as high as 798,000 dam^3 (599,000 Ac-ft.) in 1916, and as low as 327,000 dam^3 (266,000 Ac-ft.) in 1977. The mean annual discharge for the period 1911-1980 is 474,000 dam^3 (384,272 Ac-ft.). The construction of the three TransAlta Utilities reservoirs provided a total storage of 207,995 dam^3 (170,000 Ac-ft.) of which approximately 37,000 dam^3 (30,000 Ac-ft.) are considered to be dead storage. The contemporary (1932-1980) total annual mean runoff of 447,760 dam^3 (363,000 Ac-ft.) reflects a general decline in yield due to forest regeneration and a drier climate.

The regime characteristics of the Kananaskis River and a number of tributary streams changed significantly following the initial development of storage in 1933. Unlike the flow conditions prior to 1933 the post-development patterns show a much larger range in fall, winter and spring flows, and a much lower mean peak flow during the summer. For example, the monthly mean discharge during the January-March period of 10.9 cms (385 cfs) represents a three-fold increase over the 1911-1932 period. Also, the July through September streamflow results show that monthly mean flows have been reduced to below the natural extreme minimum flow values of the 1911-1932 period.

The seasonal regime patterns of the most recent 1975 to 1979 flow years are significantly different from the post-development 1933-1962 flows. The present monthly mean June flow of 15.1 cms (533 cfs) is approximately one-half the size of the 1933-1962 flow and one-quarter the size of the natural flow. In contrast, the present mean winter flows, averaging 13.6 cms (482 cfs) are approximately four times as large as the natural flows.

The contemporary mean daily patterns of streamflow are characterized by highly variable flows which reflect the use of water releases to produce peaking power. Flows have varied over 14.2 cms (500 cfs) within a 24-hour period. Flow releases from the upstream reservoirs have actually been as low as 0.056 cms (2.0 cfs).

Storage level variations in the last two decades are the result of an increasingly greater influence by seasonal power demands and changing operational strategies. Initially, in the early years of operation, the three major lakes were filled during spring runoff remained high during summer and fall, and were gradually drawn down through the winter. Currently, each lake is operated on the basis of balancing inflows with outflows to produce power, and as a result each lake has its own seasonal regime. Barrier Reservoir remains, on average, 80 percent full for eight months of the year from August to March. Drawdown begins in April through into May and by June inflows from upstream (and locally) have raised the storage to 50 percent and by the end of July to 70 percent. In contrast, Lower Kananaskis Lake has about 75 percent of its storage available from September through January. Storage withdrawal begins in February and the lowest level is reached in April. Filling proceeds from May through July where, on average, about 60 percent of the storage volume is available and the water level is 3 m (9.8 ft. approx.) from the maximum level. Upper Kananaskis Lake reaches a full supply level exceeding 80 percent on average by early October at which time drawdown begins and continues through to late February. Refilling begins generally in late May and by July the lake is, on average, about 50 percent full or 6 m (20 ft. approx.) from the maximum level.

Several aspects of the hydrology of the Kananaskis District have been affected by man's use of the water for hydro-power purposes. Lakes have been expanded or created anew to form storage reservoirs.

Rivers and creeks have been diverted, thus affecting the amount of inflow to the basin. The single purpose use of the water resources of the Kananaskis District to produce peaking power is a major cause of the daily, monthly, seasonal and annual fluctuations in water levels and streamflows. Prior to 1977, the lack of recognized competitive uses precluded the need for assessment of this management strategy. Since 1977, other competing uses for water in the Kananaskis District have been recognized in policy form and the need now exists for an evaluation of potential conflicts and alternatives to the existing water management strategy.

The effect of these low average water levels on recreational use, and on the lake environment as it influences fish and wildlife populations, is subject to debate. The potential for conflicts between competing uses (on-site recreation versus power) is quite real, and alternative strategies for management of the lakes should be examined in conjunction with the physical water supply patterns. The succeeding Chapter is an examination of this and other problems in more detail (see Chapter 5).

Chapter 5

5.0 WATER MANAGEMENT ASSESSMENT

5.1 WATER SUPPLY CHARACTERISTICS

5.1.1 Intra-Regional Climatic and Water Supply Patterns

In the previous Chapter an assessment of the spatial patterns of runoff was conducted utilizing innovative techniques developed and applied with success in water resource studies in the United States and elsewhere. The use of water balance procedures, combined with knowledge of generalized soil-water relationships, and supported with precipitation data and estimates of evapotranspiration based on available data and intuitive reasoning enables us to obtain the representative picture of natural water supply variations within the region. By dividing the Kananaskis District into 6 discrete sub-basin units as determined from flow gauge locations, a more detailed examination of the intra-regional water supply patterns was possible.

The map of runoff depicted in the last Chapter is a geographical composite of the multivariate influence of vegeation, physiography and climate on the water supply patterns. Thus the values reflect the geographical diversity of the District.

High runoff of over 90 percent of the precipitation received can be found in places along the Continental Divide and the upper ridges of the Kananaskis Range. Here precipitation amounts are the highest in the District, and runoff ranges from over 1150 mm (46 in.) up to 1500 mm (60 in.). In other areas along these major ridge systems, runoff values are also high, in the order of 875 mm (35 in.) to 1150 mm (46 in.) and represent between 70 and 90 percent of precipitation

received.

The Highwood and Elbow Pass areas also contribute almost 75 percent of the precipitation locally received as runoff; however, the total values of approximately 750 mm (30 in.) reflect less total precipitation and higher use in storage and vegetation. The intermediate valley elevations of Smith-Dorien Creek and the Upper Kananaskis River are characterized by lower runoff conditions due to several factors including distance from major ridges, deeper drift materials for greater detention storage and more extensive vegetative cover. Thus, the proportion of runoff to precipitation is approximately 50 percent representing about 500 mm (20 in.).

The main Kananaskis Valley experiences roughly similar precipitation amounts throughout although generally lower values are evident near the Evans Thomas Creek confluence and near the northern valley entrance. Here precipitation values of less than 750 mm (30 in.) are normal with values dipping to just around 500 mm (20 in.) for stations with records at Kananaskis E.S.C. and Kananaskis Boundary Ranger Station. Since the majority of this precipitation falls as rain in the summer months, much of it is used by the vegetation present and runoff amounts vary from 40 percent or 250 mm (10 in.) to less than 20 percent 125 mm (5.0 in.) of precipitation received.

On a temporal basis most of the runoff is generated in the summer months although the TransAlta Utilities reservoirs can modify the amount and the timing of release and delay runoff into the winter months. It is estimated (Laycock, 1961) that at least 75 percent of the total runoff is derived from snowmelt, although in back range areas this value is probably higher. Thus the higher areas, receiving higher amounts of winter and total precipitation, are valuable source areas for natural runoff. While the yield characteristics of the back range areas are excellent in terms of water production, the regime characteristics are poor in terms of equitable seasonal supply as evidenced in Figure 4.3a. The designation of

these same high elevation areas as good or excellent for water resources in the Foothills Resource Allocation Study (Nowicki, 1972) implies that high water yield and an inequitable seasonal distribution are desirable management goals.

In actuality, runoff from these areas is often flashy in nature and seasonally inappropriate for downstream uses such as irrigation, municipal water supply, and fish and wildlife requirements as discussed in Chapter 2. Therefore, the term 'good watershed conditions' applied to high water yield areas in the Foothills Resource Allocation Study (Nowicki, 1972) is a misnomer in terms of potential management.

In effect, the runoff regime is spatially dichotomous and temporally disproportionate within the Kananaskis District. The sharp contrast between high runoff areas, generally found along the Continental Divide and associated ranges, and the low runoff areas in the valley bottoms is mirrored in precisely the same way by the vegetative and climatic patterns in each area. Thus, the hydrologically most productive areas are found where high precipitation, low vegetative use relationships are common, which is to say along the higher ranges in the southwest of the District.

This is not meant to imply that the water management potential is small in valley areas. As the discussion in Chapter 2 has shown, these are the main problem areas in terms of water use and present and potential abuse. Current hydro electric operations are characterized by alternating high and low flow periods dependent on the need for peaking power. These fluctuations in stage and discharge disrupt the natural fishery and render the instream environment unusable and sometimes hazardous for the sport fisherman or boating enthusiast. Aesthetically, the fluctuations in water levels of the major lakes produce extensive mud flats dotted with rotting stumps. Anticipated

expansion and development of water-based recreational activities and associated infrastructures adjacent to the lake and streamside environment, will further demonstrate the need for other objectives in water management in the Kananaskis District. How water management within the District is applied will depend to some extent on the role which Kananaskis water will play in solving external water demands. A brief review of the total Kananaskis water supply contribution to the Bow River is presented below.

5.1.2 Total Water Supply Characteristics

From the discussion in Chapter 4, the contemporary (1932-1978) total annual mean runoff from the Kananaskis District is 447,760 dam^3 (363,000 Ac-ft.), which represents 16 percent of the total flow in the Bow River as measured above Calgary. On average 60 percent of this supply is generated from the high back range elevations of the Upper Kananaskis, Smith-Dorien and Pocaterra Creek watersheds. Contemporary patterns of total runoff have been influenced both by man's storage works and by a lower yield climatic period.

Historically, total annual recorded runoff has been as high as 798,000 dam^3 (599,000 Ac-ft.) in 1916, and as low as 327,000 dam^3 (266,000 Ac-ft.) in 1977. The high annual runoff value, if it is correct, indicates the influence of concentrated local storms since Bow River flow records do not show corresponding high flow values for the same period. The low flow values of the late 1930s and early 1940s can be substantiated in part by available precipitation records.

Construction of the three TransAlta Utilities reservoirs provided a total storage of 207,995 dam^3 (170,000 Ac-ft.) of which approximately 370,000 dam^3 (30,000 Ac-ft.) are considered to be dead storage (Calgary

Power Ltd., pers. comm., 1979). Given that the mean annual discharge for the period 1911-1979 is 486,000 dam^3 (394,000 Ac-ft.), the reduction can be accounted for by a general decline in yield due to forest regeneration and a drier climate.

5.2 WATER DEMAND CHARACTERISTICS

It has been shown in Chapter 2.2.2 that demands on the water resources of the Kananaskis District are comprised of both internal and external sources. Internally, water is used to provide storage for later use in hydro power production. Growing recreational uses such as boating and fishing will demand improved seasonal aquatic conditions for fish habitat, as well as for quality maintenance and improvement of lake and streamside aesthetics.

The Kananaskis River contributes on an average basis, about 16 percent or 447,760 dam^3 (363,000 Ac-ft.) of the total flow of the Bow River as measured at Calgary. Externally, this water is used to produce power in the Bow River hydro plants for the provincial interconnected energy grid. This water also contributes to the instream flows in the Bow River which are required for flow regulation and to meet minimum flow levels for water quality protection. Municipal and industrial demands exercise a steady increase on withdrawals of Bow River waters, particularly in and around Calgary. The three irrigation districts which withdraw water from the Bow River below Calgary place the greatest demand on the water supply, a demand which increased substantially in the 1970s. Finally, Bow River water is used, in conjuction with the Oldman and Red Deer Rivers, to meet the Apportionment Agreement which gives one-half the natural flow originating in the South Saskatchewan River Basin or 2.6 million dam^3 (2.1 million Ac-ft.), whichever is larger on a calendar year basis, to Saskatchewan.

The ensuing discussion is an examination of the nature of each demand in terms of its actual or potential effects on the daily, seasonal or annual Kananaskis District water supply. This will allow for an unbiased assessment of the potential conflicts in water use given the present water management structure, and it also provides the basis for determining the viability of these same demand uses when under different water management objectives

5.2.1 Internal Water Demand Requirements

The existing internal water management strategy in the Kananaskis District is to provide storage for later release to the Kananaskis and Bow River hydro plants for power production. The sequence of flow releases from the Kananaskis Lakes and Barrier Reservoir is determined for the most part, by demands for power. The flexibility of hydro operations and their capability of near-immediate response to requests for power generation, mean that hydro produced power handles much of the peak energy demand on a daily, weekly or even monthly basis. The impact of this management strategy on lake levels and streamflow was discussed briefly in Chapter 2.2.2 and illustrated for the period 1975 to 1978 in Figures 2.2d and 2.2e.

The daily demands on streamflow are such that fluctuations in flows up to 4.0 cms (176.6 cfs) are quite common throughout the year, although they are most noticeable in the low-flow summer period. In 1980, streamflow measured below Lower Kananaskis Lake actually varied from 0.227 cms (7.98 cfs) to 10.8 cms (379.5 cfs) within a 24-hour period. On a weekly or montly basis, streamflow below Lower Kananaskis Lake has varied over 20 cms (703 cfs) in 1980 (Environment Canada, 1981). The seasonal demand on streamflow for power production is best represented by the hydrograph depicted in Figure 5.2a. In this graph, the monthly mean streamflow values are averaged over the most recent 6-year period.

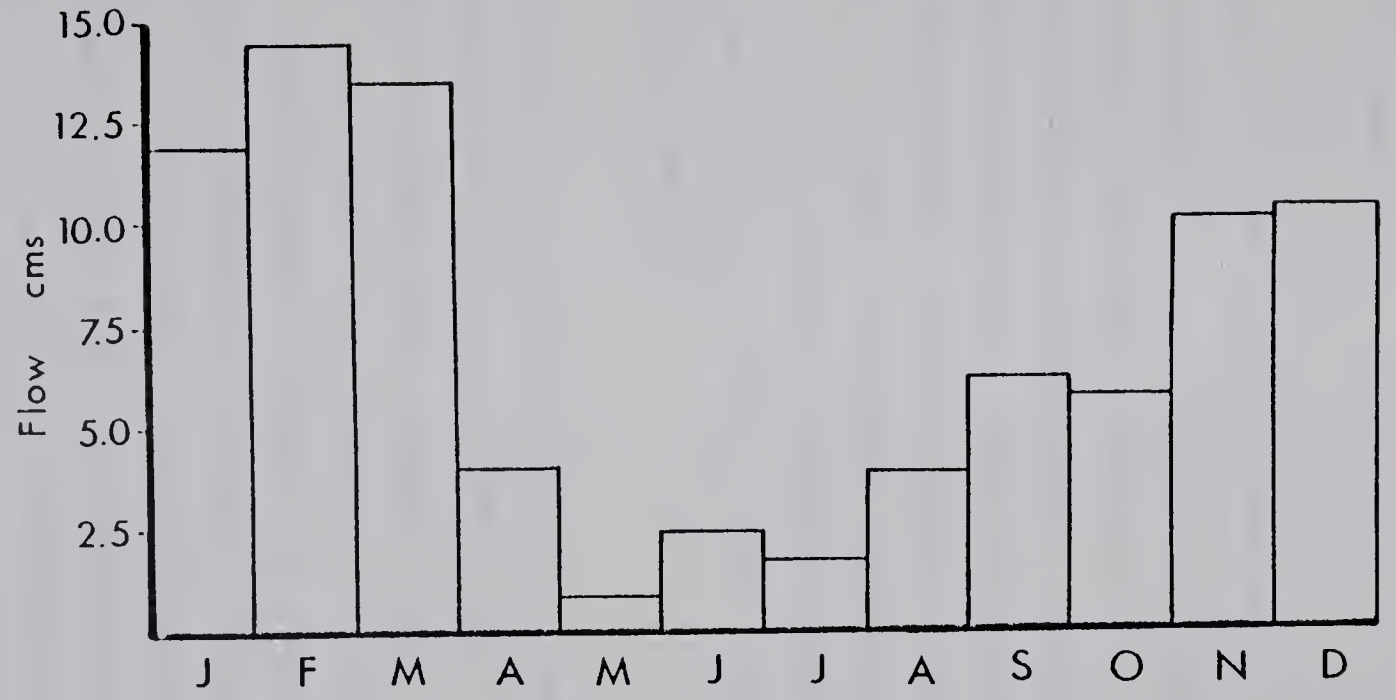


Figure 5.2a Monthly Mean Streamflow, Kananaskis River, Measured Below Lower Kananaskis Lake, 1975 - 1980.

Source: Environment Canada, 1980, 1981.

and it is clear that the majority of flow occurs over the winter months of November through to March. This time period coincides well with the net peak energy demand within the provincial interconnected energy grid as illustrated for the 1969 - 1980 period in Figure 5.2b.

The winter seasons peak energy demand is also the reason for the storage patterns exhibited by the reservoirs. Figure 5.2c depicts the contemporary 1969-1980 seasonal mean monthly water levels for the three storage reservoirs. A significant amount of storage is utilized in the months of November through to February from Upper Kananaskis Lake and much of this replaces water spilled from Lower Kananaskis Lake and Barrier Reservoir. The information contained in Table 5.2a shows the most recent 1980-81 changes in energy potential (hence, energy demand) for each of the three reservoirs on a monthly basis. The trend is clearly related to seasonal energy demand and natural rates of inflow, the latter being of more significance during the May through to August period.

The contribution which the Kananaskis hydro plants have made to the interconnected electrical grid has steadily declined since 1970, due to the construction of additional thermal coal plants. Although the total net annual generation of the Barrier, Interlakes and Pocaterra plants was not significantly different in 1980 from 1970 levels, the amount contributed to TransAlta Utilities total generation, and to the Alberta interconnected system, has declined by more than half to the levels indicated in Table 5.2b. This decline is also mirrored by a similar decline in the net annual contribution by all hydro plants from 13 percent of the provincial total generated in 1970 to 7.75 percent of the provincial total generated in 1980. (Alberta, Energy Resources Conservation Board, 1980). This should not, however, be interpreted to mean that the hydro operations are not an important component of the generation system, or that their use in the future may be limited. On the contrary, as discussed in Chapter 2.2.2, the

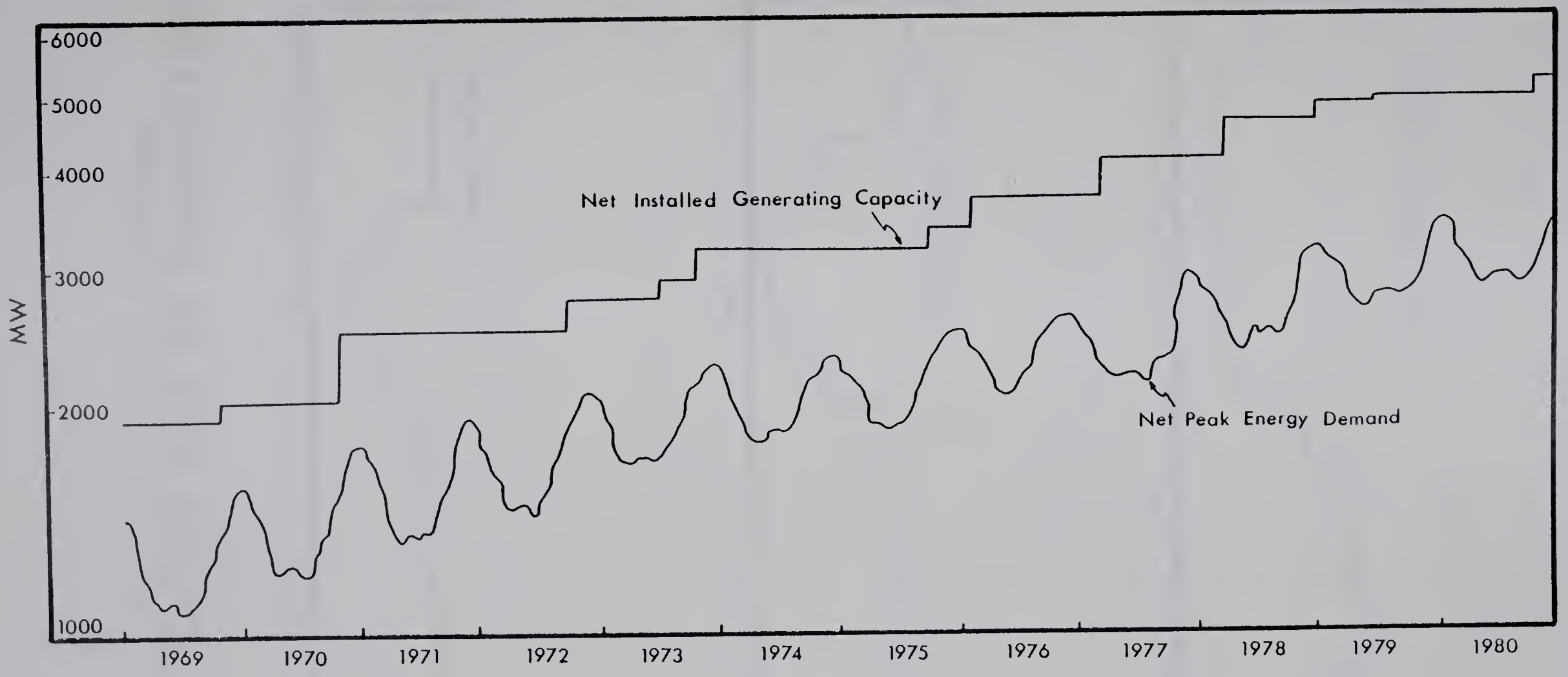
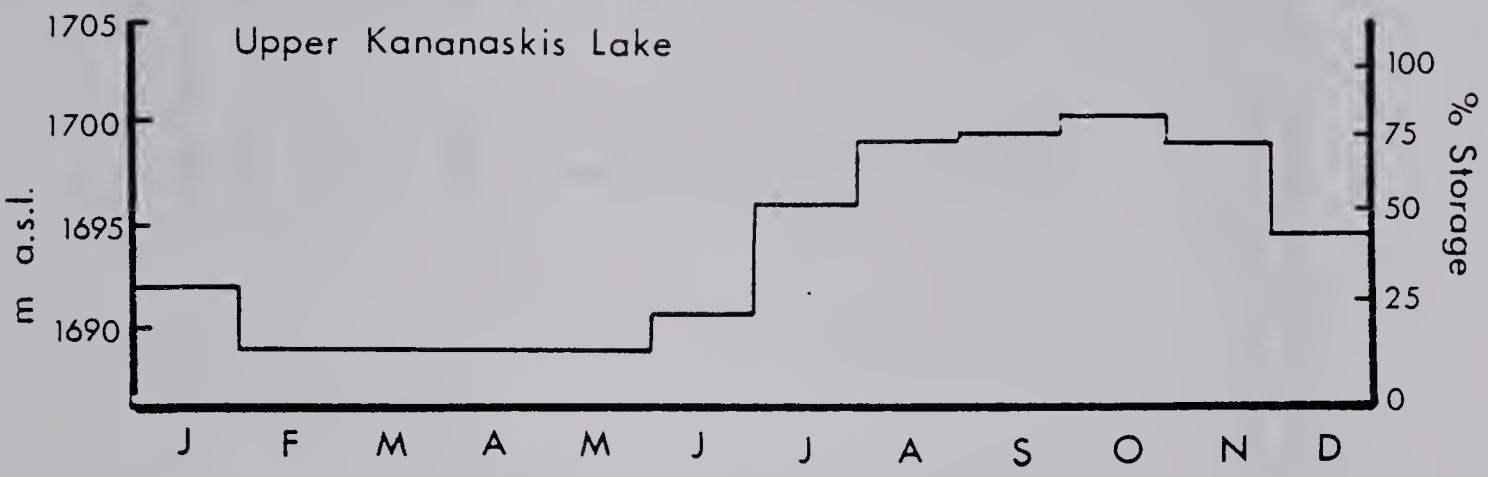
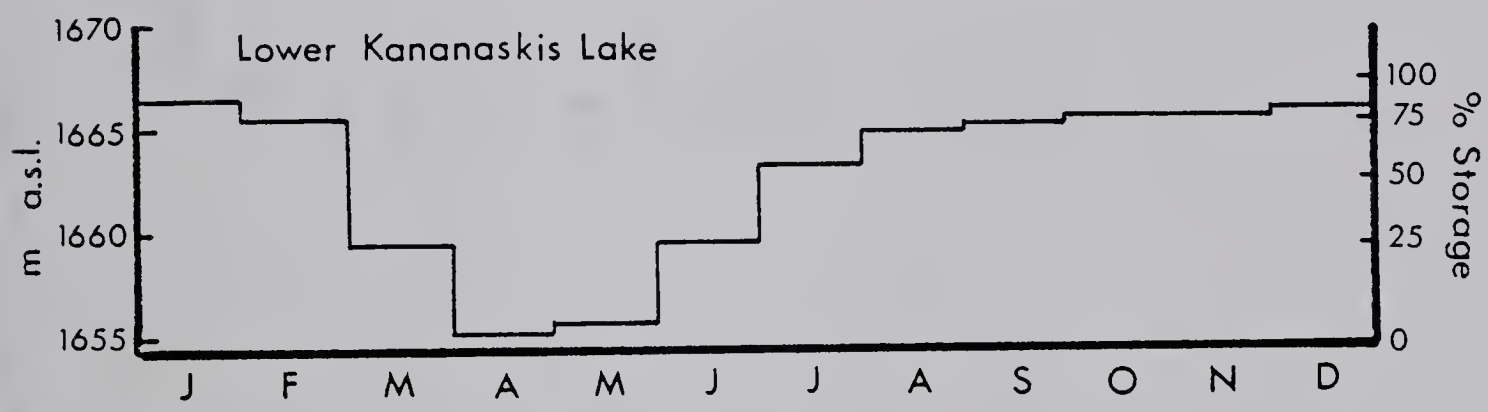


Figure 5.2b 1969-1980 Alberta Interconnected System Demand and Generating Capacity

Source: ERCB, 1980.





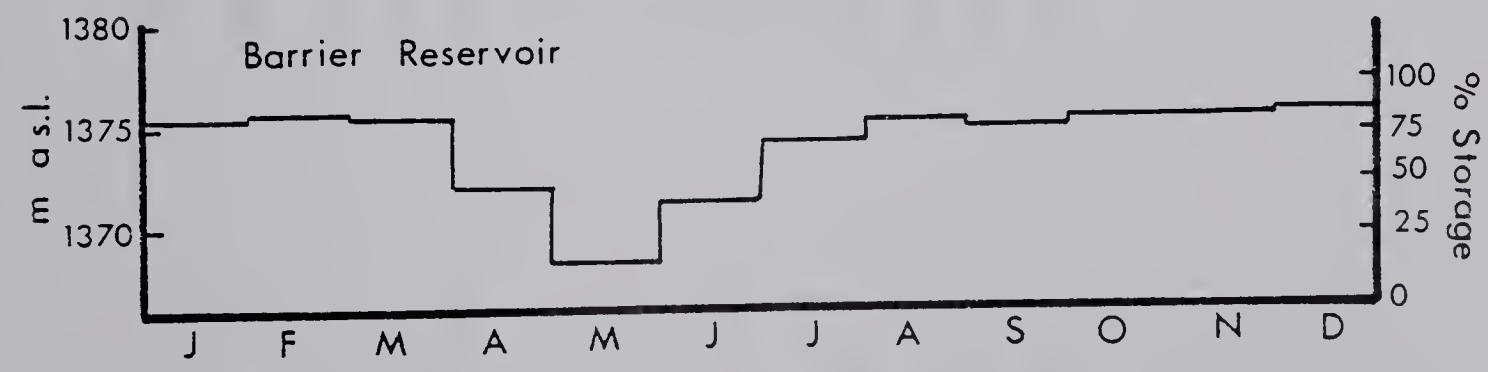


Figure 5.2c 1969-1980 Mean Monthly Water Levels for Upper and Lower Kananaskis Lakes and Barrier Reservoir.

Table 5.2a

Hydroelectric Energy Stored in Kananaskis District Reservoirs
at Month End in 1980 and 1981

	Upper Kananaskis Energy (GWh)		Lower Kananaskis Energy (GWh)		Barrier Energy (GWh)	
DATE	1980	1981	1980	1981	1980	1981
January	20.7	10.9	20.5	10.7	7.0	7.3
February	14.2	10.4	14.8	0.4	7.1	7.4
March	7.3	10.7	7.6	1.3	6.6	7.0
April	3.4	11.7	7.5	2.6	5.7	5.3
May	13.0	20.8	19.3	11.2	5.9	4.4
June	28.3	32.3	19.9	17.2	5.3	4.8
July	41.2	52.3	21.3	21.5	5.9	5.1
August	52.4	56.6	21.8	23.7	6.6	6.7
September	55.7	56.0	21.4	25.1	6.8	6.1
October	46.7	49.3	24.8	25.0	6.7	6.6
November	31.9	33.9	24.1	25.9	6.6	6.6
December	15.6	22.9	24.3	24.5	7.2	7.1

Source: Alberta, Energy Resources Conservation Board, 1980, 1981

Table 5.2b

Net Annual Generation (GWh) of the Kananaskis District Hydro Plants
1970 - 1980

PLANT	70	71	72	73	74	75	76	77	78	79	80
Barrier	41.8	37.8	52.9	36.7	50.9	37.3	45.3	32.6	42.9	33.6	46.5
Interlakes	9.6	7.5	10.9	6.3	10.6	7.1	9.2	6.5	7.9	8.4	10.0
Pocaterra	31.2	28.1	38.7	23.9	37.4	25.9	34.3	25.3	28.8	25.3	34.2
TOTAL	82.6	73.4	102.5	66.9	98.9	70.3	88.8	64.4	79.6	67.3	90.7
% Total TransAlta Generation	1.49	1.13	1.41	0.88	1.12	0.81	0.93	0.57	0.66	0.48	0.59
% Total Alberta Intercon-nected System	0.89	0.71	0.87	0.52	0.73	0.49	0.59	0.88	0.44	0.33	0.41

Source: Alberta, Energy Resources Conservation Board, 1981

demand for electrical energy is forecast to increase 7.7 percent annually, from 3700 MW in 1980 to 6650 MW by 1988, as illustrated in Figure 5.2d. Even though the total amount of reserve generating capacity will remain about the same over this time period, its proportion of the total generating capacity will decrease by almost half (Electric Utility Planning Council, 1981). Since the hydro operations are flexible enough to provide either load control, peak demands, or both, they will undoubtably continue to provide a similar seasonal contribution to the Alberta interconnected system. As such, the seasonal demand on the storage and flow systems of the Kananaskis District will continue in the near future as they have during the 1970s.

A consequence then, of using the Kananaskis Lakes and River system for hydro power production in a peaking mode, will be a continued low volume of streamflow during the summer period marked by abrupt and large increases of flow at intervals coinciding with peak daily demands for energy. In addition, relatively large and consistent streamflows will characterize the winter months when seasonal and peak daily demands for energy are at their highest. The Kananaskis Lakes and Barrier Reservoir will continue to be drawn upon to provide the storage necessary for use later in power production. The seasonal pattern of drawdown and fill sequences will mean water levels will be below optimum (full supply level) for most of the summer period reaching near-optimum levels by late August. The extreme temporal variations in streamflow and lake levels may pose significant limitations on potential users of the water resources in the Kananaskis District.

Officially, recreation demands on the land and water resources of the Kananaskis District, are embodied within the Policy for Recreation Development of Kananaskis Country. Unfortunately, no mention is made in the Policy of the role which water management will play in the recreational developments which are outlined, and were discussed in Chapter 2.2.1. Sport fishing is mentioned as the major

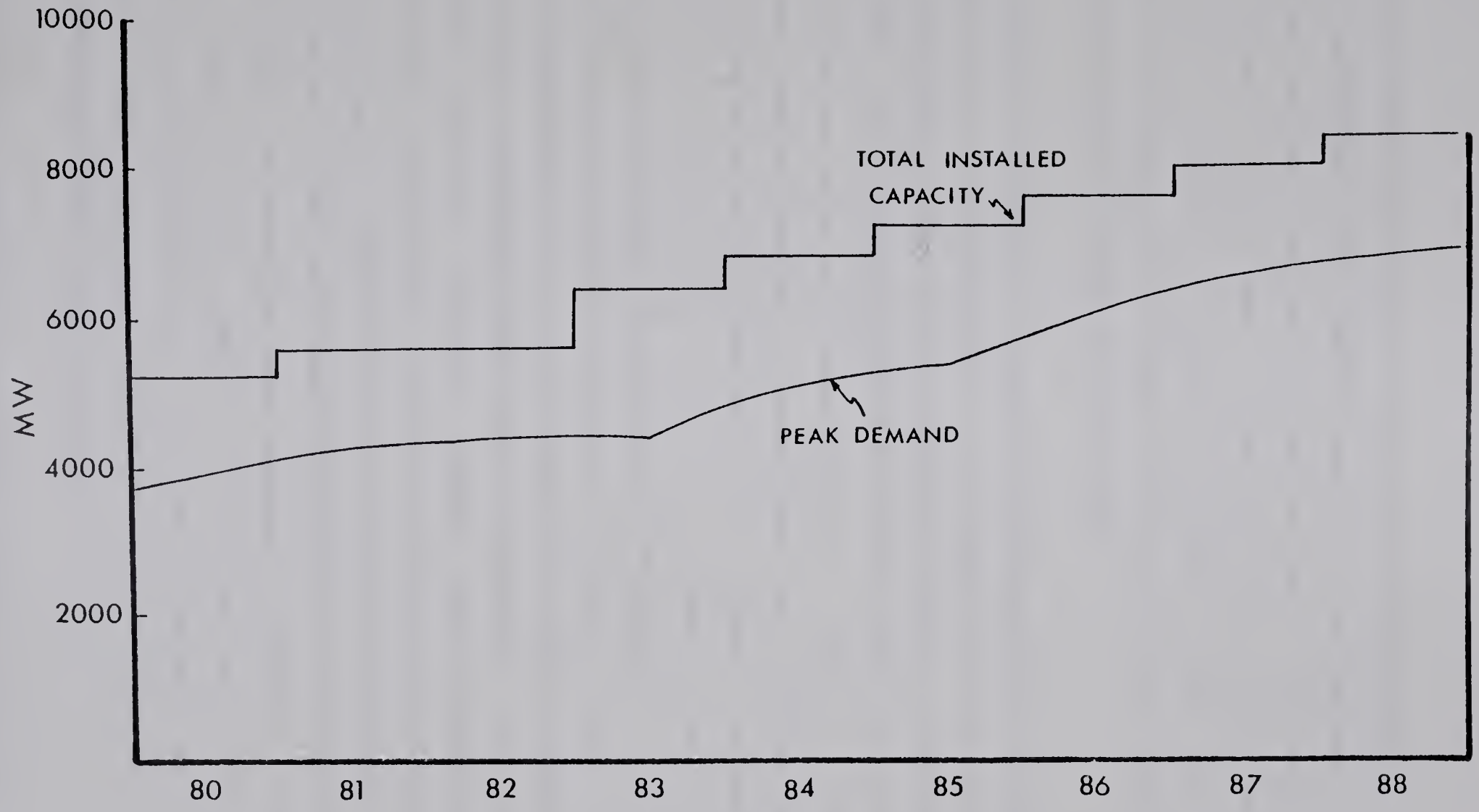


Figure 5.2d Approved Total Installed Generating Capacity for Alberta 1980 - 1988.

Source: Electric Utility Planning Council, 1980.



water-based recreational activity which will be encouraged in Upper and Lower Kananaskis Lakes, Barrier Reservoir, the Kananaskis River, and numerous smaller lakes and tributary streams. Boat ramps are to be constructed at Barrier Lake in association with the planned day-use area to provide for boating and fishing in that lake. Ramps are also to be constructed at Upper and Lower Kananaskis Lake to enourage boating and fishing in these lakes.

In concert with sport fishing and boating, aesthetic viewing of the lakes and rivers of the District is deemed to be a major focus of the recreational goals of the government (Alberta, Recreation and Parks, 1977). This is substantiated by the fact that several major camping or day use areas are planned adjacent to Upper and Lower Kananaskis Lakes, Barrier Reservoir, Evans-Thomas Creek, Ribbon Creek, and the Eau Claire site on the Kananaskis River. There is no mention in the Policy as to how the full realization of these recreational activities will be affected by the existing water management structure which is determined largely by TransAlta Utilities. There are no specific recommendations in the existing Policy which designate the water levels or streamflows which would be desirable for these recreational activities. There is, however, tacit recognition in the Policy that the reservoirs and river will continue to be operated for hydroelectric purposes (Alberta, Recreation and Parks, 1977). The implication is that water-based recreational activities will be conducted within the existing water management framework. However the review in Chapter 2.2.2 has suggested that actual use of the water resource for the activities noted above may be hampered due to a combination of present management orientations and the vagaries of regional climate and water supply patterns.

Unofficially, impending recreational demands particularly for sport fishing, have been the focus of internal government studies (Alberta, Energy and Natural Resources, 1980). Concerns have been expressed,

principally by the Fish and Wildlife Division of the Department of Energy and Natural Resources, that the existing water management strategy is having a negative impact on fish production, as well as the aesthetic recreational appeal of the riverine system. At the present time, no quantitative alternatives to the current streamflow patterns have been suggested, although several potential instream flow methodologies are in existence elsewhere, and could prove useful here. Ongoing studies are being conducted to identify policies and management strategies to amend the 5-year old Policy for Recreation Development in Kananaskis Country. It has been suggested that a recommendation may be forthcoming to facilitate a more flexible mode of operation which is responsive to recreational and fisheries needs(Alberta, Energy and Natural Resources, pers. comm., 1982).

Aside from the participatory recreational demands on water, there will be withdrawals in support of the recreational service infrastructure installed in campsites and the alpine village. No data are available on the volume of withdrawals, but it is likely they will be drawn from local groundwater sources and only minor surface use will occur. Since the local tills in the valley bottoms are likely to be saturated due to a high retention storage capacity, there are few anticipated problems with this practice. A small reduction in water quality associated with a higher phosphorous and faecal coliform counts may occur locally, but proper waste water management can reduce this to minimal levels.

There are other demands on the water resources of the Kananaskis Distirct, but they are less tangible and more difficult to quantify. In many ways, the recreation demands discussed above are complemented by the demands for assured supplies of good quality water for man, animals and fish and for a vibrant streamside environment which supports aquatic wildlife and provides desirable aesthetic values. Yet there is a definite need to quantify the requisite levels of streamflow required to sustain the aquatic habitat and promote a healthy

stream and streamside environment for wildlife and recreationists alike. There is no existing instream flow methodology being used to determine desirable flow levels in the Kananaskis, Bow or South Saskatchewan River Basins, yet several are being examined by the Fish and Wildlife Division for use in other river basins (MacLaren Plansearch, pers. comm., 1982). For the purpose of providing a perception of what the daily, monthly, and seasonal instream flow demands might be for the Kananaskis River, the most regionally appropriate instream flow methodology now in use in the United States was selected and applied. The use of the methodology is not and endorsement of it versus other types, but rather it is used here to show how instream flow demands might be presented, and further it provides a basis for determining how these flow demands might be affected by varying water management objectives and operational strategies.

The assessment of the suitability of instream flows for fisheries and other aquatic habitat users has been based on the so-called Tennant Method (Tennant, 1976). The purpose of the Tennant Method is to provide quantitative guidelines on the necessary instream flows required to sustain fish, wildlife, recreation and related environmental resources. After 20 years and hundreds of studies of the relationships between the physical, chemical and biological characteristics of rivers in Montana, Nebraska and Wyoming, it was found that the condition of the aquatic habitat is remarkably similar on most streams carrying the same portion of the average annual flow (Tennant, 1976). The results of the analysis are recommended flow regimen which determine the capability of the stream to support the fisheries and other resources mentioned above. Table 5.2c lists the recommended instream flow proportions based on various levels of capability in sustaining environmental resources. The seasonal split is a response to the higher flow requirements for fish during the spring spawning period and summer movement period.

Table 5.2c

Instream Flow Regimens for Fish, Wildlife, Recreation
and Related Environmental Resources

NARRATIVE DESCRIPTION OF FLOWS *	RECOMMENDED BASE FLOW REGIMENS	
	OCT.-MAR.	APR.-SEPT.
Flushing or maximum	200% of the average flow	
Optimum range	60% - 100% of the average flow	
Outstanding	40%	60%
Excellent	30%	50%
Good	20%	40%
Fair or degrading	10%	30%
Poor or minimum	10%	10%
Severe degradation	10% of average flow to zero flow	

*Most appropriate description of the general condition of the stream flow for all parameters listed in the title of this paper.

(From: Tennant, 1976)

Essentially, the Tennant method recognizes three major threshold flow regimes. Ten percent of the average flow is a minimum instantaneous flow required to sustain short-term survival habitat for most aquatic life forms. Thirty percent is recommended as a base flow to sustain good survival conditions for most aquatic life forms and general recreation. Sixty percent provides excellent to outstanding habitat for most aquatic life forms during their primary periods of growth and for the majority of recreational uses. The actual instream characteristics of each of the above threshold values are described below in brief.

With 10 percent of the average flow the stream sub-strate or wetted perimeter would be about half exposed, except in wide shallow riffle or shoal areas where exposure could be higher. Side channels would be severely or totally dewatered, and gravel bars and islands would be substantially dewatered and would usually no longer function as wildlife resting, denning, nursery or refuge habitat. Streambank cover for fish and animals would be severely diminshed, and many wetted areas would be so shallow they no longer serve as cover for fish. Water temperatures would rise, encouraging fish to congregate in deeper pools where they are more vulnerable to over-harvest. Invertebrate life would be severely reduced. Floating by boat or rafting is difficult due to persistent shallows and the natural beauty and stream aesthetics are degraded.

With 30 percent of the average flow, the majority of the river substrate will be covered with water except for very wide, shallow shoal areas. Most side channels will carry some water and many gravel bars and islands will be partially covered with water providing adequate spawning, nesting, nursery and refuge habitat. Fish will be able to move over riffle areas with sufficient cover, and water temperatures would be moderated due to higher flows and overhanging streamside vegetation. Invertebrate life is not expected to become a limiting factor in fish production. Water quality and quantity should be good for fishing, floating and general recreation

and stream aesthetics will be satisfactory.

With 60 percent of the average flow available, excellent to outstanding habitat is provided for most aquatic life forms. In addition, water quality and quantity are excellent for recreational use, particularly fishing, boating, rafting and canoes, and stream aesthetics are enhanced.

There are several recommendations which further clarify the operational constraints under which the instream flows would be managed. Tennant (1976) drew attention to the need for 'instantaneous flows', to prevent flow releases from dams which are averaged over a day, month or year which permit erratic releases or even no releases at times. In addition, reduced releases to a stream should not exceed a vertical drop of 150 mm (6.0 in. approx.) within a 6 hour period. Fluctuations greater than this could expose fish and other aquatic streamside users to insufficient cover for feeding, nesting or refuge. Also, the maximum flows released from upstream structures should not exceed twice the average flow. Prolonged releases would result in bed and bank scouring, endangering spawning and nesting areas, and increasing sedimentation of the water supply causing a deterioration in water quality.

Some comment is required on the Tennant method before discussing its 'application to the Kananaskis River.' The Tennant method, along with several others, was developed as a result of the need to quantify instream flow requirements as part of the 2nd United States National Water Assessement in 1974 (Bayha, 1978). It was recognized that correlating hydrological data with biological needs would be difficult, and that developing approximations of the instream flow requirements based upon judgement and the best information available was the preferred option to not quantifying instream

flow needs at all. The application of the Tennant and other instream flow methodologies during the National Water Assessment, was aimed not at making the final decisions on the allocation of water resources, but at identifying the problems and conflicts between various users (Bayha, 1978). Similarly, use of the Tennant method in this study is directed primarily to developing, in a quantitative and graphical format. the approximate seasonal instream flow requirements to support the habitat of aquatic life forms and outdoor water-based recreation.

To demonstrate the use of the Tennant method for determining instream flow requirements for the Kananaskis River, the stretch of river above Barrier Lake was chosen for examination. Since fishing is advocated in the provincial government's Policy for Recreation Development, as being an important resource and recreational pastime in the Kananaskis District, it is important to see how these uses will be influenced by present strategies of water management. Figure 5.2e illustrates the natural mean daily flows per month of the Kananaskis River above Pocaterra Creek. The flow values were derived from data prior to 1942, after which significant changes in storage and seasonal flow releases took place, as described in Chapter 4.2.1 and 4.3.1. The hydrograph in Figure 5.2e illustrates a slightly modified natural flow system as the initial 37,000 dam^3 (30,000 Ac-ft.) of storage in the Upper Kananaskis Lake is used to store some of the spring runoff. However, the seasonal pattern of flows is similar to the hydrographs presented in Chapter 4.3.1, and therefore is used here as a pseudo-natural flow so that the Tennant flows can be calculated. The recommended Tennant flows are calculated as a percentage of the average annual discharge, and then plotted as instantaneous daily flows. For this study, two instream flow levels were calculated and plotted; the 40 percent/20 percent summer-winter flow level which is recommended for good fish habitat conditions and the 10 percent/10 percent summer-winter which is recommended as the minimum flow conditions required to maintain the least acceptable

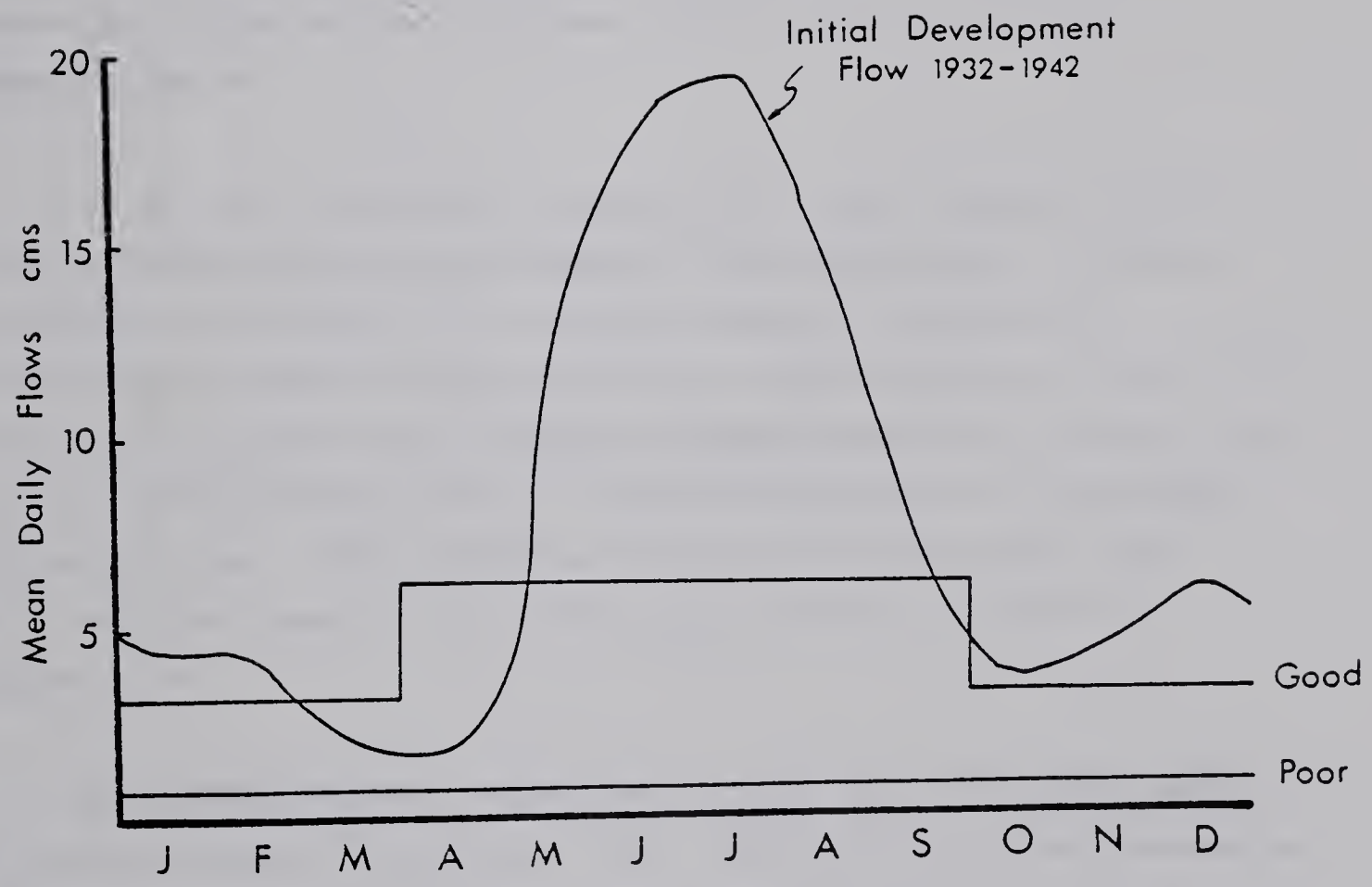


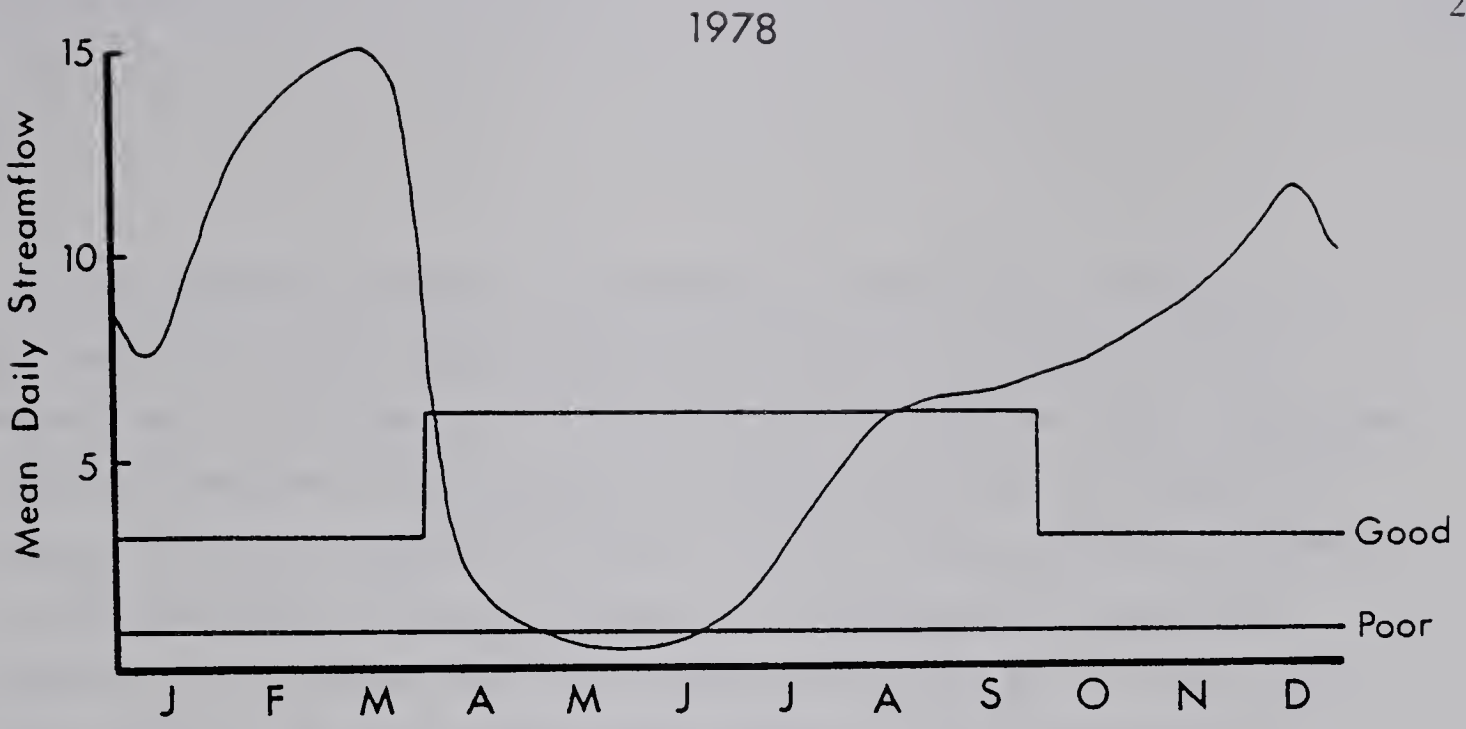
Figure 5.2e Comparison of Average Daily Flows and Calculated 'Tennant' Flows Required for Fish Habitat in the Kananaskis River.

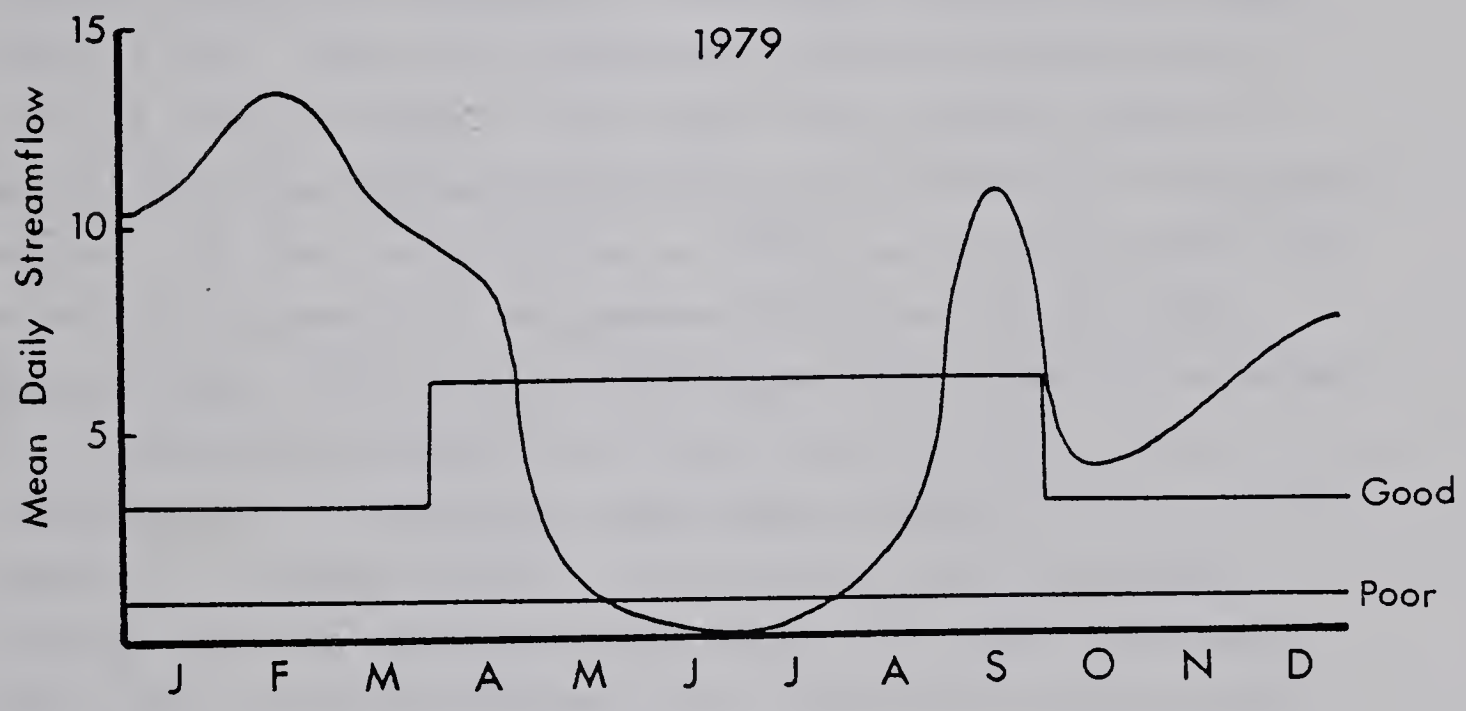
aquatic conditions for fish habitat and recreational uses.

The natural flow level depicted in Figure 5.2e meets or exceeds the recommended instream requirement for good fish habitat in 10 out of 12 months. Only during the March through early May period does the daily flow fall below the 'good fish habitat' level, yet it remains above the minimum desired level. However, it is during the April-May period that some spawning would occur, and the lower than desirable flows which normally occur at this time might adversely affect the spawning process by exposing gravel bars. Therefore, even the natural flow system could be improved upon, if it was deemed desirable to ensure good fish habitat instream flows during the spring spawning period.

The actual contemporary instream flows have changed from the natural conditions due to a change in water management strategy by TransAlta Utilities. The percent seasonal storage and streamflow patterns are representative of the strategy of producing peaking power, and the flow releases depicted in Figure 5.2f for the 1978,1979 and 1980 flow years are evidence of the changed regime patterns. The calculated Tennant flows are those that were developed based on the natural flow system presented in Figure 5.2e.

The extreme seasonal variation in mean daily flows per month is clearly evident from Figure 5.2f. This pattern is representative of the winter demand for extra base load power and for meeting the peak load requirements in any season. However, when compared to the Tennant flows it is obvious that there is a seasonal conflict in demand. The mean daily flow drops below the 40 percent Tennant flow in April and generally stays below until late August or September, although flow releases were large in September in 1979 and June of 1980. Therefore during the summer period, the present water management strategy is at odds with fisheries and water-based recreational requirements.





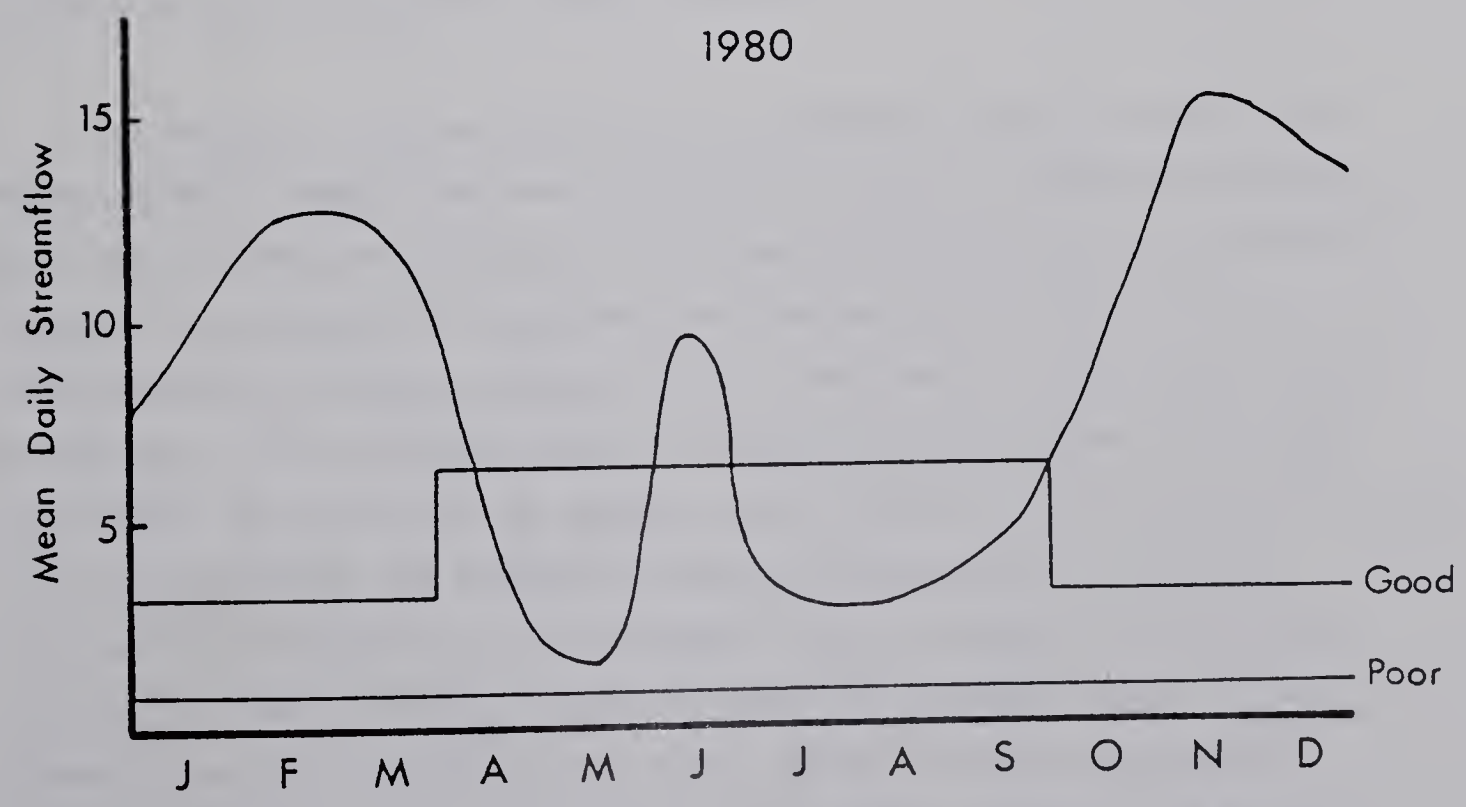


Figure 5.2f Comparison of Actual Mean Daily Flows in the Kananaskis River with Recommended 'Tennant' Flows for Fish Habitat.

The seasonal nature of streamflow is even more erratic during the crucial summer period when the flow records are examined on a daily basis. For instance, in 1978 the daily mean flow release from the Pocaterra plant averaged 0.057 cms (2.0 cms) or less on 10 days in April, 25 days in May, 24 days in June, 18 days in July and even 13 days in August. Yet because of mean flow releases which often vary from 0 cms to as much as 15.0 cms (527 cfs) within a 24 hour period (see Chapter 4.3.3) the monthly averages appear less damaging to the aquatic habitat than they probably are. Given the recommended Tennant minimum flow of 0.79 cms (28 cfs approx.) the present flow strategy fails to ensure even this minimum requirement for fisheries and the aquatic habitat. In fact, only in June of 1980 does the mid-summer flow exceed the minimum flow requirement 50 percent of the time, while in June 1979 the mean daily flows fail completely to exceed the recommended minimum flow. If one were to look at the availability of consistent instantaneous minimum flows, as recommended by Tennant (1976), it is obvious that the present strategy of water management practised by TransAlta Utilities would fail to meet the minimum flow required by fish and other aquatic users during the summer period.

In summary, the suitability of instream flows for fish and other aquatic users has been assessed using the 'Tennant Method'. This method was used primarily to develop quantitative comparisons between the available flows and the recommended instream flow requirements to support aquatic life forms and outdoor water-based recreation. The analysis shows that the natural flow levels are sufficient in 10 out of 12 months with only the pre-spawning period flows being below the desired levels providing good fisheries and aquatic conditions. The present flow strategy, as evidenced by 1978 to 1980 records, fails to meet the desired level of instream flows for fisheries and other aquatic users including recreationists in most days during the summer period. In most

summer months, and particularly in June 1979, the flow releases fail to reach even the recommended minimum flows advised for maintenance of the fisheries and aquatic habitat. The institution of any aquatic management strategy, using flow criteria similar to those described above, will ultimately be in direct conflict with the present operational strategy of TransAlta Utilities. The compatibility of the Tennant instream flow methodology with alternative water management objectives will be examined in Chapter 5.3.

5.2.2 External Water Demand Requirements

The most important external demand requirement which influences the water management strategy of the Kananaskis District is that of energy demand. The actual daily and seasonal operations of TransAlta Utilities have been dealt with in the previous section; however, there are several other power demand considerations which could affect how the hydro system in general, and the Kananaskis system in particular, are operated. These are described briefly below.

The hydro generating capacity in Alberta measured 15.43 percent of the provincial total in 1980, yet produced 7.76 percent of the energy for that year. As new thermal stations are commissioned, such as Keephills 1 and 2 in 1983 and 1984, Sheerness 1 and 2 in 1985 and 1986, and Genesee 1 and 2 in 1987 and 1988, the proportion of hydro produced energy will continue to shrink. Therefore, hydro produced energy will be used to meet more of the daily and seasonal peaks in demand, and less for seasonal load control. This type of operation can only accentuate the daily peaks in streamflow which were described in Chapters 2.2.2 and 4.3.3, and which it has been suggested are less than ideal

for fisheries and water-based recreation.

Currently, TransAlta Utilities is studying potential sites where hydro development, or increases in existing in-place hydro generating capacity are feasible. The first site is Dunvegan, on the Peace River approximately 88.5 km (55 miles) north of Grande Prairie in the northwest part of the province. A preliminary study of this site indicated a generation potential in the area of 1,000 megawatts (TransAlta Utilities, 1980). The second site is at Mountain Rapids on the Slave River, in the extreme northeast corner of the province a few kilometres south of the Northwest Territories boundary. The potential generating capacity is estimated between 1,200 and 1,500 megawatts. The third and fourth sites are the existing Bighorn and Brazeau hydro sites on the North Saskatchewan River. Present flow restrictions at both the Brazeau and Bighorn sites result in a loss in generating capacity of 165 megawatts (TransAlta Utilities, 1980).

Detailed feasibility studies have been or are in the process of being completed, for the Dunvegan and Mountain Rapids sites. Although the potential 2500 megawatts of generating capacity is not needed at the present time, the Electric Utilities Planning Council (1981) predicts that both these sites will be developed by the year 2005. TransAlta Utilities is, however, proposing to increase the peaking power output during the winter time from the Brazeau and Bighorn generating stations (Wierenga, 1982) in the near future. The Renewable Resources Study Group, a public advisory committee to the Environment Council of Alberta, has come out strongly against TransAlta's proposal. The study group cites the severe fluctuations in water levels as being responsible for scouring of the stream bed by ice and by varied flow rates, rendering the river almost useless for spawning by fish (Wierenga, 1982). In addition, the vague wording of the operating license is blamed for not providing any means for regulating the size of flow releases.

Certainly, there are parallels in the operations of the Brazeau/Bighorn hydro plants and the Kananaskis River hydro plants, and similar potential problems. The Province of Alberta is ultimately responsible for ensuring that Brazeau/Bighorn operations dc not cause flooding in the areas downstream. However, the lost generating capacity at the Brazeau/Bighorn stations is costing TransAlta Utilities millions of dollars in operating revenues each year. Politically, the Province has several options: it can approve the extra releases subject to implementation of flood protection procedures downstream, it can refuse the extra releases; it can defer a decision until later with the hope that other more attractive sources of energy become available; or it can seek a compromise in which trade-offs are discussed which give both the province and the company a benefit. One possible tradeoff might include allowing for increased releases in the North Saskatchewan from the Brazeau/Bighorn project, in return for more measured releases in the Kananaskis River where recreation and fisheries are recognized in Policy form as important resources. The 32.8 MW of generating capacity in the Kananaskis District could be easily made up for by allowing even half of the unused 165 MW capacity at the Brazeau/Bighorn to be exploited. Since TransAlta would still be receiving the benefit of run-of-river flows, no actual loss in generating revenue need occur. The demand curve for water from the Kananaskis District would change from the hydrograph depicted in Figure 4.3h to one of more measured daily releases and a more equitable seasonal regime. This is, of course, clearly dependent on several factors which cannot be discussed in detail here, yet it is a valid point that such a tradeoff is within the realm of possibility and therefore exists as a potential external factor which could influence the demand for water from the Kananaskis District. This topic will be dealt with more specifically in the following section.

In concert with TransAlta Utilities' other reservoirs in the Bow River basin, Kananaskis River water is used to help sustain instream flow levels and water quality in the Bow River. The flow guidelines in place are consistent throughout the year, that is, there is the same minimum flow guideline in effect in June as in December. Traditionally, it has been desireable to maintain a minimum flow in the Bow River at Calgary of 39.6 cms (1400 cfs) to ensure water quality standards. Releases from the upstream reservoirs have been largely responsible for maintaining streamflow near or above this level during the naturally low flow winter period. As a result, in the Bow River above Calgary, nutrient concentrations and algal levels remain low throughout the year (Alberta Environment, 1981b). Generally, total suspended solids measure less than 5.0 mg/l above Calgary, which is well below the 10.0 mg/l level recommended for use by fish or public recreation. In addition, turbidity levels measure less than 10 JTU as compared to the minimum recommended level of 25 JTU, dissolved oxygen measures 85 mg/l as compared to the recommended minimum of 5.0 mg/l and pH registers between 8.0 and 8.5, well above the recommended minimum of 6.5 (Alberta Environment, 1981a). Industrial wastewaters are discharged to the Bow River upstream from Calgary by two chemical industries and three natural gas processing plants, none of which contribute any significant effects on Bow River water quality (Alberta Environment, 1981a).

Diverse monitoring activities carried out on the Bow River downstream of Calgary clearly demonstrate excessive nutrient enrichment of the river. Water chemistry data indicate that nutrient parameters, and to a lesser extent phenolics, oil and grease, and bacterial counts do not meet Alberta Surface Water Quality objectives in this river reach (Alberta Environment, 1981a). High levels of both phosphorus and nitrogen are evident during the low flow winter months, while these same levels are appreciably reduced during spring and early summer due to dilution by in-

creased river flows and uptake by the biological communities. Macrophytes, which take up phosphorus, grow profusely from Calgary to Bassano and cause aesthetic problems. These rooted aquatic plants diminish the aesthetic appeal of the river and are the principal cause of the large diurnal and seasonal fluctuations in the dissolved oxygen concentration which places added stress on the sport fish population (Alberta Environment, 1981a). Macrophyte growth starts in early May, declines during the high flow month of June, then re-establishes itself until senescence in mid-September.

Measurements of benthic algal production rates show substantial increases downstream from Calgary with the highest rates in the basin measured near Carseland. The observed change in community structure downstream of Calgary is related to dissolved nutrient levels, which are depleted to the limits of detection in the lower reaches of the basin (Alberta Environment, 1981b). The low mid-summer nutrient levels and extremely low flows in the Bow River near Bow City combine to further reduce the algal growth (Alberta Environment, 1981b).

An inventory of the sources of phosphorous which contribute to the water quality problems in the basin identified contributions from municipal sewage treatment plants, storm sewers, industries and irrigation return flows. Approximately 70 percent of the total phosphorous entering the reaches of the Bow River downstream from Calgary was found to come from the Calgary municipal storm and sanitary sewer system, with the sewage treatment plants accounting for about 58 percent of this total between May and October (Alberta Environment, 1981a). Sewage effluents then, are the most significant adverse influence on water quality in the Bow River downstream from Calgary.

Water quality and instream flow demands above Calgary are satisfied by the existing practice of attempting to maintain a minimum flow of 39.6 cms (1400 cfs). Monitoring activities downstream of Calgary have shown that excessive concentrations of nutrients, phenolics, oil and grease and bacteria often exceed provincial water quality guidelines during the May to October period. A higher level of streamflow during this period would help dilute the nutrients to levels where uptake by macrophytes is hindered, as it is during the high flow period in May. However, it is more likely that a concerted effort to reduce the releases of nutrients at their source, particularly from the sanitary and storm sewer systems, will be implemented. The City of Calgary has commmitted itself to reducing the contributions of phosphorous to the Bow River from 58 percent of the total to 28 percent by 1982 (Alberta Environment, 1981a). Occasionally, public concern has been expressed regarding the quality of the Bow River downstream from Calgary. When high levels of bacteria or other substances render the water unfit for bodily contact, regulatory agencies currently advise water users to exercise common sense in their activities. TransAlta Utilities may experience pressure from these regulatory agencies to increase Bow River flows during periods when water quality standards are not met. However it seems more likely, based on past experience, that additional requests for flows in excess of the present minimum will only take place after all other measures such as chemical control or removal, or warnings governing use, have been tried. The municipal and industrial water deamnds on Bow River supplies represent a significant short-term withdrawal. The current license allows for a withdrawal equivalent to 4.8 percent of the Bow River's average flow at Calgary of 2,910,000 dam^3 (2,359,140 Ac-ft.).

However, less than half this amount has been taken in the previous 3-year period (1979-1981). By 1988 it has been forecast that the annual water demand by the City of Calgary will have reached its present license limit on the Bow River, necessitating an increase in the license withdrawal. Further increases in the license limit at the level forecast for the year 2001 shows that only 8.5 percent of the average annual flow of the Bow River will be withdrawn for use. Measurements by the City of Calgary's engineering department and Alberta Environment show that approximately 80 percent of the water withdrawn for use is returned via the sanitary sewer system. In addition to the return flow in the sanitary sewer system, there is a major contribution to the Bow River from the storm sewer system. Changes in land use are responsible locally for larger yields which have been estimated for storm sewer and storm water retention ponds to comprise between 37,000 dam^3 (30,000 Ac-ft.) to 49,340 dam^3 (40,000 Ac-ft.). Thus the volume of water returned to the Bow River from both the sanitary and storm sewer system may exceed the actual total amount consumed for use.

This is not meant to imply that municipal demands are an insignificant external demand on the water resources of the Bow River basin. On the contrary, the demand for water is 30 to 40 percent higher and growing in Calgary than in similar sized centres, and this is attributed to the flat-rate charge for water for residential customers. With fewer than 20 percent of Calgary's single family homes having water meters, the flat-rate charge for water actually encourages overuse. Partly due to this, in addition to increases in population, are the large peak daily demands for water which just fell short of the capacity of the Bearspaw delivery plant in 1979. Because of this, millions of dollars have been committed by the City of Calgary to exapand the Bearspaw water plant to meet the peak demand of the 1980s and 90s.

Almost 50 percent of the consumptive use by the City of Calgary takes place in the months of June through August. This time period coincides with the heavy domestic use of water for lawns, car washing and other home related uses causing significant losses to evaporation or the storm sewer system. This accounts for the fact that return flows in mid-summer comprise about 60 percent of the initial demand, as compared to over 90 percent during the remainder of the year. The actual municipal demand is small in comparison to the average year and even the dry year supply, representing about 2 percent of the flow in the Bow River measured at Calgary. The peak municipal demand period falls within the peak flow period of the Bow River and thus the demand is satisfied by water of sufficient quantity and quality. The present system of operation of the Bow River reservoirs in evening out the seasonal flow supply complements the present and forecasted municipal demand.

Although the short-term withdrawals of water by the City of Calgary are relatively small in terms of total Bow River flow and are largely replaced over time by return flows in both the sanitary and storm sewer system, the quality of the return flow has been shown to be less than ideal for some downstream uses. For use orientations such as sport fishing, boating, swimming, fish habitat or human consumption, Bow River flows below Calgary have not been of sufficient quality in some years to meet even the minimum provincial guidelines. The City of Calgary is attempting to rectify some of the nutrient enrichment loading problems by upgrading the phosphorous removal capability of the sewage treatment plants. The volume of the return flow is certainly of use in meeting the provincial obligations of the Apportionment Agreement. However, instream users of the water downstream of Calgary might argue that the return flow is often useless and should be supplemented by upstream releases during periods when water quality guidelines are violated. While this

argument creates an artificial demand for water which might conflict with current operational patterns, it is more likely that efforts will be directed more to controlling and limiting the releases of nutrients and other chemicals.

Irrigation demands by the three irrigation districts which withdraw water from the Bow River represent the largest, and legally the most contentious demand. It is the irrigation demand which receives special status in that:

> "the Minister of Environment can direct that the rate at which water is being impounded in the Bow River Reservoirs be reduced for such periods as to preserve the legal rights granted under the Irrigation Act."

and,

> "the Minister can direct that releases be made from the Ghost Reservoir for a period of 10 days in total to maintain the flow at 130 cms (4,600 cfs) if it is required for irrigation."

(Dybvig, 1979)

The assessment of irrigation demands in Chapter 2.2.2 revealed that irrigation in 1980 in the EID, WID and BRID withdrew almost 40 percent of the available Bow River flows or 1,208,200 dam^3 (979,490 acre-feet). In a dry year such as 1977 the flow in the Bow River between Calgary and the Bassano Dam was depleted by irrigation withdrawls from 2,100,000 dam^3 (1,702,500 acre-feet) to 449,000 dam^3 (364,000 acre-feet). The larger demand in 1977 and lower volume of return flow meant that flow at the mouth of the Bow River measured 1,390,000 dam^3 (1,126,900 acre-feet) or 43 percent of the mean annual flow. Although some return flow from the Bow River is transferred to the Red Deer and Oldman River Basins for subsequent use in meeting the Apportionment agreement of the South Saskatchewan River, it is apparent that in a dry year the irrigation demand may exceed the required instream contribution of the Bow River.

Figure 5.2g illustrates the monthly disposition of flow during the irrigation season in the Bow River at both sites compared to the minimum flow required for instream water quality protection. It is clear that in a dry year where Bow River flows are below normal and irrigation demands are high, that actual instream flows will be below the recommended limits and that other uses may suffer. In 1977 the total diversion of all irrigation districts in Southern Alberta amounted to 2,140,100 dam^3 (1,735,000 Ac-ft.) and yet only 20 percent of this total was measured as return flow (Barnetson, 1981).

At present there is sufficient water in the Bow River during the irrigation season in an average flow year to satisfy irrigation demands into the 1990s and still meet the downstream Apportionment Agreement. This assumes no change in the rate of irrigation expansion (currently averaging 4 percent per year), or in the efficiency of water delivery and application systems. However, in meeting the present day irrigation demand even in an average flow year, the remaining flow as measured below the Bassano Dam is severely depleted. For example, in 1980 mean daily Bow River flow through Calgary measured 87.0 cms (3072 cfs), 67.4 cms (2380 cfs) and 64.6 cms (2281 cfs) in July, August and September respectively. Yet below the Bassano Dam these same months have a mean daily flow of 28.2 cms (995 cfs), 30,1 cms (1062 cfs) and 20.3 cms (716 cfs) respectively. Therefore, the stretch of the Bow River below the Bassano Dam suffered from a lack of sufficient flow necessary to meet the Provincial government's minimum flow quality guideline of 39.6 cms (1400 cfs). The low flows below the Bassano Dam would seriously affect other uses including water based recreation, sport fish habitat and stream environment conditions. The eutrophication studies cited in an earlier section found that the low flows are conducive to high concentrations of nutrients which in turn support healthy macrophyte populations which degrade the stream environment and adversely influence sport fish habitat (Alberta Environment, (1981a). The thick weeds make swimming unpleasant, and fishing and

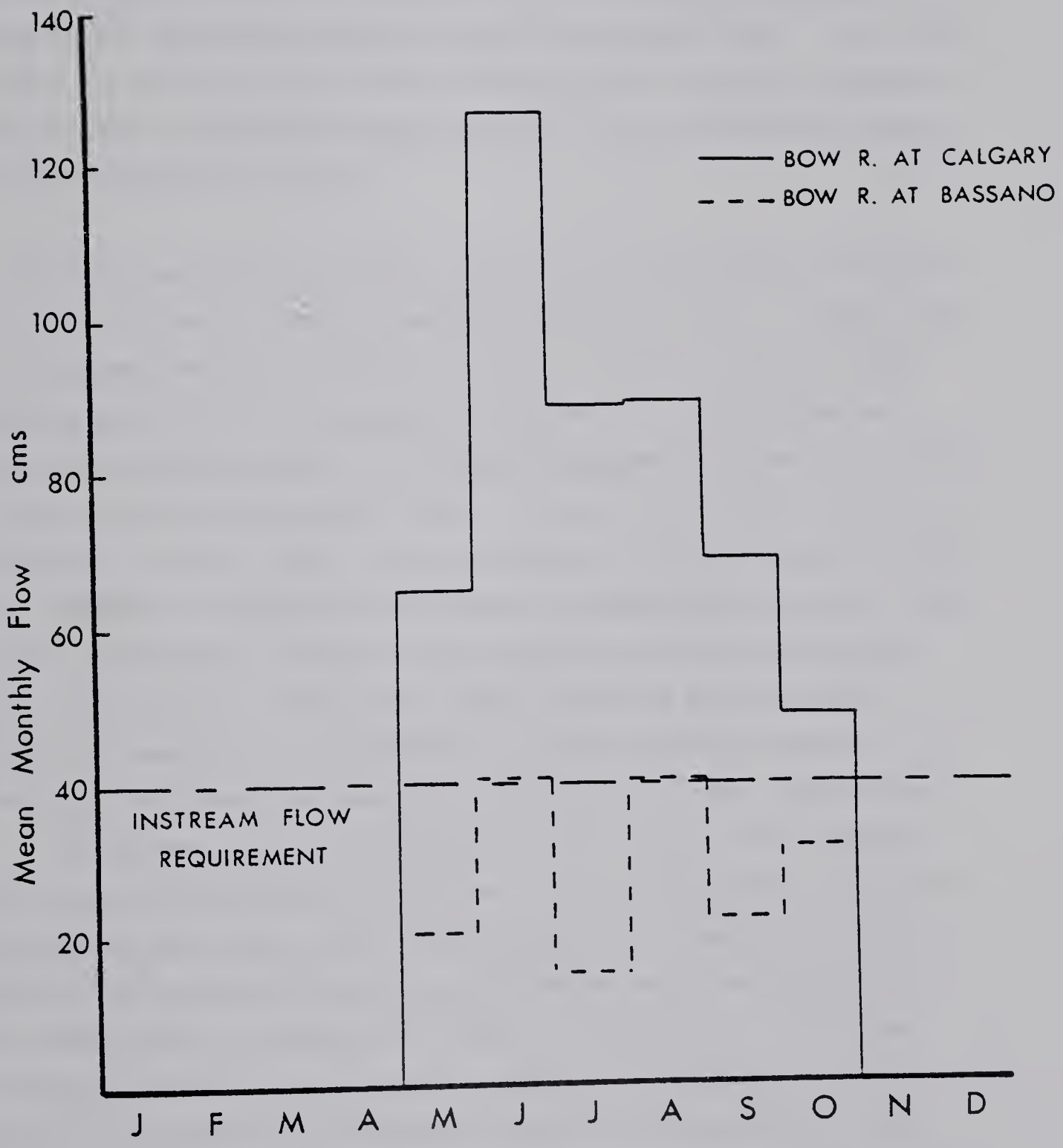


Figure 5.2g 1977 Dry Year Bow River Flow and Minimum Instream Water Quality Requirement.

boating less than desirable. Although the return flows from the irrigation districts supplement Bow River flow such that daily mean flows are acceptable or marginally acceptable, there is no doubt that severe stress is exerted on the stream environment in the Bow River in stream channels below the Bassano Dam. In a dry year such as 1977 when the supply patterns show similar declines during the peak irrigation demand period, the environmental problems become even more acute.

There are several potential alternative management strategies which would influence the irrigation demand and some of these have been discussed earlier in Chapter 2.2.2. Ideally there are two approaches which could be studied to alleviate the problem of insufficient instream flow; 1) either increase the supply of water, or 2) decrease the demand for water. There are several ways in which either of these goals can be achieved. Water supplies could be supplemented by releases from upstream reservoirs; however this would interfere with TransAlta's operations and would certainly require negotiation. Additional water supplies might be made available if municipal consumptive uses are reduced; however the savings here would be small and unlikely to have a major impact on downstream flows. Management of the upper basin headwaters areas using either vegetation or snow management principles might produce some extra yield as discussed in Chapter 2.1.2; however it is unlikely that these increases would be significant in dry years when the demand for water is greatest. Providing for storage from wet to dry seasons might be an option and the Provincial government has examined a few of the available sites (ie. Forty Mile Reservoir in the Oldman Basin); however, the potential here is not large. The use of groundwater supplies to supplement surface flow during low flow periods might be of use if local geologic conditions are amenable; however the volumes of water available are not thought to be large in the Bow River Basin. The most significant method of increasing water supply is to transfer from regions with a surplus and provide the storage

facilities to maintain this extra water from wet to dry years. Such an alternative has been proposed before but the lack of proper demand studies and a general feeling of public uncertainty helped to kill the project. The renewal of this topic at recent symposia in Alberta would lead one to believe that it is being studied to determine the feasibility of such an undertaking.

The water demand for irrigation uses could be cut back using any one of several alternatives. In dry years, a priority restriction could be placed on crop types so that only the high value cash crops benefit and others like alfalfa are grown using conventional dryland techniques. Increasing the cost of water to the user would help to encourage conservation, thereby reducing demand and indirectly ensuring that only those crops that are worth the additional cost will benefit. Decreasing the number of hectares brought under irrigation each year could be managed by the irrigation districts to ensure compliance and ultimately reduce demand. Perhaps the most significant method of reducing demand could be attained if an improvement in the current level of water use efficiency was improved. Even a doubling of the level of efficiency to 70 percent of the water diverted for use might help reduce the demand by a similar proportion. Such a program might seek to replace existing canals with concrete based structures to prevent seepage. Also, the method of application might be adjusted to reduce evaporative losses by spraying downward or spraying during the evening and early morning when air temperatures are lower.

If present (1975-1980) trends in the growth of the number of hectares irrigated proceeds for the remainder of the 1980s at a rate of 4 percent per annum, and the withdrawal of water increases at approximately the same rate, then water supplies will be strained towards the end of the decade in an average flow year. In a dry year where supplies are limited yet demands are higher, return flows may not be sufficient to maintain the instream flow

above the provincial minimum or to provide the necessary proportion of flow for downstream Apportionment.

The Apportionment agreement stipulates that Alberta must pass along one half of the natural flow of the South Saskatchewan River Basin or 2.6 million dam^3 (2.1 million acre-feet), whichever is largest on a calendar year basis. In an average flow year the Bow River contributes about 3,210,000 dam^3 (2,602,350 acre-feet) to the South Saskatchewan River. The present demands on the system are such that in an average flow year the Apportionment agreement is easily satisfied. However, with a dry year flow such as that experienced in 1977 and with the present level of withdrawals, particularly for irrigation, the agreement comes close to not being fulfilled by Alberta. In 1977 the actual flow contributed by the Red Deer, Oldman and Bow River measured 3,130,000 dam^3 (2,537,500 Acre-feet) which is 40 percent of the normal annual discharge. As the amount of land irrigated increases and the total volume of withdrawals grows the likelihood of a potential violation of the agreement during drier than normal conditions increases.

Other pressures on the existing agreement could come in the form of changes in the time period. The province of Saskatchewan had earlier sought to re-negotiate the agreement to redress the seasonal imbalance in flows. However the province of Alberta rejected this idea, knowing that allowing for increased flows during this summer period would be largely at the expense of the irrigation districts, unless of course corresponding increases in releases were forthcoming from the upstream reservoirs. Since this latter option would affect TransAlta's existing operations it would no doubt be opposed vigorously unless it could be shown how the company would benefit by such a change.

Altogether, the external demands on the water of the Kananaskis -Bow River system comprise several different sources, each with its own special temporal or spatial requirement. Attempts to satisfy these demands in the past have been more or less successful largely due to an abundance of water in any area. Recent years have seen several problems identified due to increasing demands from municipal and industrial sectors and from environmental concerns over water quality and quantity. Since the demand requirements for the major users identified above are different, the ultimate objectives of each user concerning management of the headwaters might also be different. The following section will define the range of possible objectives based on the demand and supply problems outlined above and suggest alternative strategies in water management.

5.3 ASSESSMENT OF WATER MANAGEMENT ALTERNATIVES

5.3.1 Choosing a Regionally-Based Water Management Objective

The provincial government's Policy for Resource Management of the Eastern Slopes, released in late 1977, clearly stated that the overriding water management objective was to be protection of existing watershed conditions (Alberta, Energy and Natural Resources, 1977). On the surface, this appears to contrast markedly with the policy advocated 30 years earlier by the governing Act which established the Eastern Rockies Forest Conservation Board. At that time the management objective was described as being one of obtaining the greatest possible flow (ie. yield) in the Saskatchewan River and its tributaries (Swanson, 1977). This apparent shift in management orientations has less to do with changes in demand patterns than with poorly defined objectives. As discussed in Chapter 1, the need for water yield increases from the Eastern Slopes has never been specifically expressed by any government agency, provincial or federal although it is suspected that the Prairie Farm Rehabilitation Act may have spawned the original interest (Hanson, 1973). Since no need had been established for additional supplies of water, it is highly probable that the governing Act simply wanted to ensure that supplies did not decrease due to man's actions. Similarly, during the 1973 Environment Conservation Authority hearings into resource use in the Eastern Slopes, briefs presented to the hearings strongly emphasized public recreation opportunities and the need for enviromental protection of this important water producing area (Alberta, Energy and Natural Resources, 1977). The policy of watershed protection implies impunity from change, which will come under increasing pressure as both internal and external demands for water increase as described in Chapters 2.2 and 5.2.

Also the objective of watershed protection, associated as it is in the Policy with the high water producing areas of the region, is aimed at minimizing any reduction in yield due to anticipated uses. Thus the two policy statements are, in essence, suggesting that the status quo be maintained, since no water demand studies have been undertaken which show the need for any changes (ie. increases) in the water supply patterns.

There are of course good reasons why the application of such a water management objective to the Kananaskis District is inappropriate. First of all, as discussed in Chapter 1, a blanket management objective such as watershed protection which is applied to diverse geographic areas within the Eastern Slopes, ignores the unique inter-regional water supply/water demand patterns and it is unreasonable to assume that protection must be stressed in all mountain and foothill regions. More specifically, the application of watershed protection in the Kananaskis District is directed at ensuring that potential land use practices do nothing which damage the environment or reduces the water yield from the area. However, much of the water yield is produced at higher elevations, due to higher precipitation and less utilization in soil moisture recharge or vegetation. These higher elevation areas are generally bare rock or colluvial in nature and it is difficult to imagine how these areas could be damaged in any way that would affect runoff characterisitics. The term 'good watershed condition' used to describe these high elevation/high water producing areas in the Kananaskis District and elsewhere in the Foothills Resource Allocation Studies is a misnomer because it is difficult for these areas to be bad in terms of water yield. Yet the regime characteristics from these areas can be bad since runoff in the spring and after a rainstorm is often flashy, high in sediment and may cause localized flooding. The term is also a poor choice for it fails to identify from a demand perspective, potential management problem areas. Certainly, some of the valley areas, while not great producers of water, stand to experience the heaviest use pressures associated

with recreational demands on water. Current physical water supply patterns are such that conflicts in use will arise between the various demands and there is a need to develop the framework for resolving conflicts.

Therefore, the management objectives which have so far been applied to the Kananaskis District, and much of the rest of the Eastern Slopes, have not been in response to either perceived demands or potential problems. The water demand review conducted for this study clearly shows that there are numerous demand configurations which are vying for a proportionally fixed volume of water, and that there are indications of present and potential problems which will complicate the disposition of use of this water.

Choosing the optimum water management objective for any region should be based on which demand or demands society deems to be of most worth. Obviously, society's perception of worth can change with time and circumstances. Also demand configurations can change with time, as we have seen with TransAlta Utilities, where peaking power production has become the main function of the hydro system operations in the 1970s and 80s versus the load control function in the 1950s and 60s. Since changes can occur in the nature of the demand, whether it is for hydro power or water-based recreation, the need for flexibility in choosing management objectives is paramount. However, policies on water management in the last 30 years in the Eastern Slopes have been anything but flexible, as monotonic objectives such as protection are emphasized. The current entrenchment in government policy of protection for large areas of the Eastern Slopes, including the Kananaskis District, does not offer encouragement for a responsive approach to water management problem resolution.

The range of potential water management objectives has been reviewed in Chapter 2.3. The viability of any of these objectives in terms of applicability to the Kananaskis District, depends to a large extent on the physical ability of the region to accommodate them. Put another way, a basin with a high water yield which more than satisfies demand requirements yet has serious erosion and sedimentation problems would benefit from a management program which sought to minimize these problems, instead of focusing on ways to improve water yield. In the Kananaskis District these objectives are examined below for compatibility with the physical reality of the basin and then evaluated in the next section against a range of alternatives which might influence future management decisions (see Table 5.3a).

The potential for yield improvement within the Kananaskis District depends on the ability to either increase precipitation falling on the catchment or decrease evaporation losses from the basin. On a theoretical level, the most dependable way of increasing the volume of water running off a catchment is to increase the amount of precipitation falling on it. Cloud seeding has been carried past the theoretical stage and actually field tested in the Western United States in conditions similar to those of the Eastern Slopes (U.S. Department of Interior, 1971). Results from several years of study (Leaf, 1975) have shown that an increase in snow equivalent to 55 mm (2.2 inches) of water yield was produced in the Fraser Experimental Watershed during these tests. However, the study has also shown that the extra precipitation cannot be precisely controlled geographically. Whether similar results could be achieved in the Kananaskis District is difficult to predict. It is probable that at a fairly high level on the western slope of the Continental Divide, condensation would be increased near summit areas and winter snows would carryover downwind. This situation would be best for water yield purposes since a relatively large portion of the extra precipitation would be available as streamflow. However, because of the unpredictability

Table 5.3a

Potential Water Management Objectives and Alternative Techniques for use in the Kananaskis District

	OBJECTIVE	TECHNIQUE	FEASIBILITY
a)	Yield Improvement	- weather modification	- unknown
		- snow management	- limited increases at high elevations
		- vegetation management	- minor increases in some years
		- storage additions	- generally unavailable
b)	Regime Improvement	- reservoir operations	- offers maximum flexibility
		- pumped storage	- not cost effective
		- vegetation management	- limited potential
		- forest fire limitation	- long-term benefit
c)	Quality Maintenance and Erosion and Sedimentation Limitation	- reservoir operations	- good potential to minimize peak flows
		- forest fire limitation	- long-term benefit
		- regulate land clearing	- good potential
d)	Flood Limitation	- forest fire limitation	- long-term benefit
		- reservoir operations	- little unused storage available
		- zoning flood-prone areas	- limited since valley areas are more heavily used
e)	Stream Environment Improvement	- forest fire limitation	- long-term benefit
		- reservoir operations	- good potential to moderate flows and lake levels
		- regulate land clearing	- good potential
		- vegetation management	- some benefits from maintenance of stream-side vegetation

of airflow patterns in summit areas this alternative will not be given serious consideration until other, more easily predictable alternatives have been exhausted.

Modifying the distribution and duration of stay of snow on the ground has been a major effort in water yield research. In the alpine zone above treeline the emphasis has been on snow fencing as a means of snow drift management. The premise is that snow which accumulates in deep drifts, undergoes metamorphosis and is less susceptible to redistribution and experiences a slower melt, thus prolonging streamflow into late summer periods. Martinelli (1964, 1965a, 1965b, 1972) demonstrated the potential for alpine snowmelt retardation to increase summer streamflow by snow fencing methods in Colorado. For several years 3.0 m (10 ft.) fences at carefully selected sites have added 42 cubic m (1500 cubic ft.) of snow for each lineal equivalent of fence and increased average depth by 2.0 m (6.5 ft.), as measured on July 1. Over a length of approximately 30 m (100 ft.) this was calculated to provide almost an extra 1200 cubic metres (42,860 cubic feet) of water. This success was achieved only after considerable study of the interaction between topography and wind patterns.

Fisera (1977) reported on the results of a study using vegetative - snow fencing in areas of tree islands in the alpine zone in Marmot Creek in the Kananaskis District. The results proved inconclusive in terms of snow accumulation and water yield due, in part, to the structure of the tree islands, which were not adequately stocked.

It is clear from research that, for snow management in the alpine area of the Kananaskis District to be feasible, several conditions must be met. First, is an area of consistently high snowfall of at least 750 cm (300 in.) or better. Second, the right

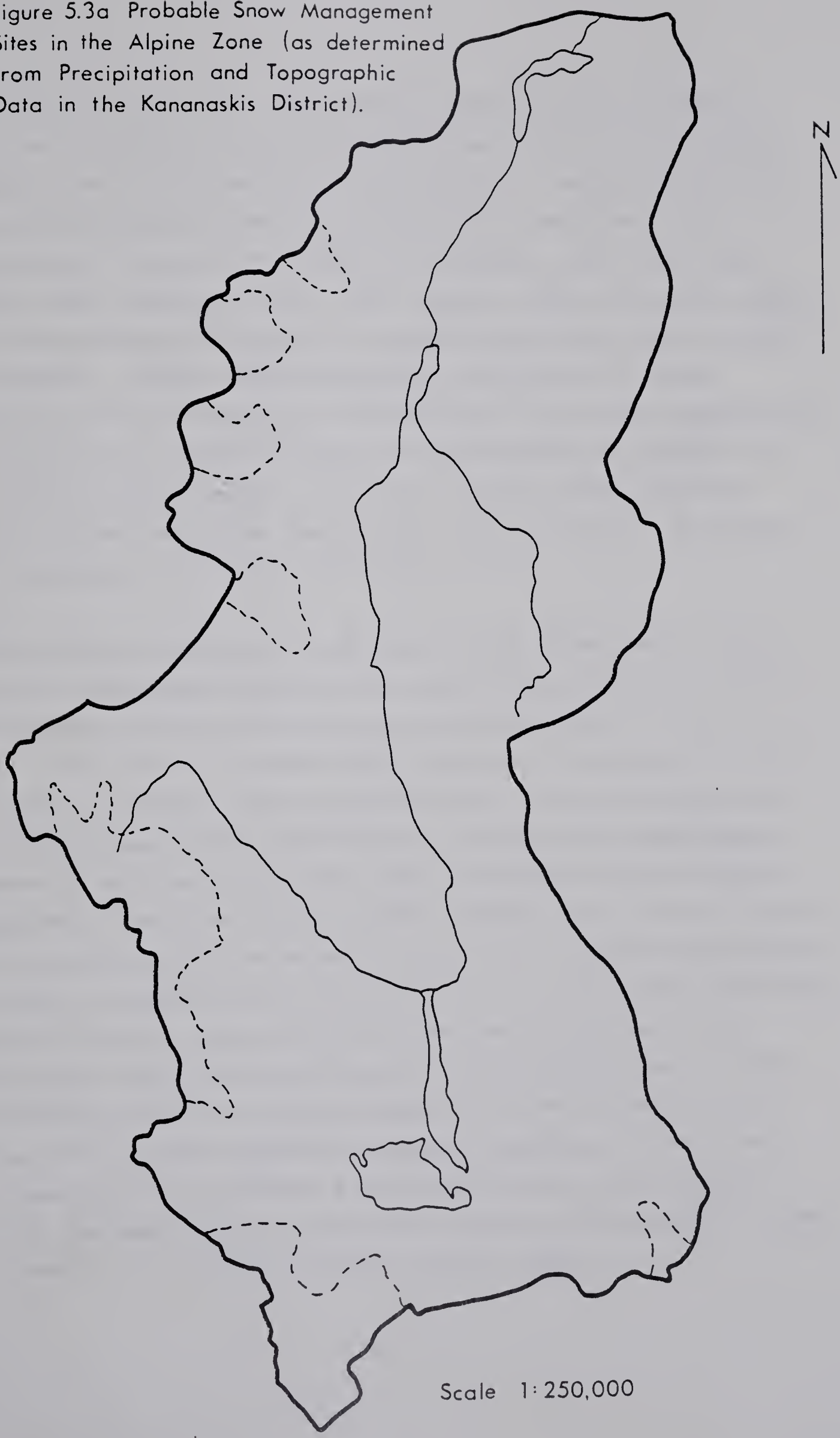
combination of topography and winds, such that broad expanses of open areas with a northeast aspect dip below sharp ridges whose apex runs perpendicular to the prevailing winds. Third, is a high elevation which reduces temperatures and thus prolongs snow retention and release to streams. Using physiographic and precipitation maps the most favourable sites for alpine snow management in the Kananaskis District are shown in Figure 5.3a.

One of the key problems with applying research results from Colorado concerning alpine snow management is the difference in area above 3050 m a.s.l. (10,000 ft. a.s.l.). In Colorado there are extensive broad plateau-like land areas at and above this elevation where much of the research is conducted (estimates range upwards of 800,000 hectares (2 million acres)). Martinelli (1965b) collected much of his data from the Loveland Basin in Colorado above 3660 m a.s.l. (12,000 ft. a.s.l.).

In the Kananaskis District, no meteorological information is available for elevations above 2745 m a.s.l. (9000 ft. a.s.l.) where alpine management schemes would be feasible. The areas indicated on Figure 5.3a are those which combine the best elements of precipitation and physiography. Certainly, the areas adjacent to the Haig and Mangin glaciers are suitable sites, however, considerable research into wind and snow drift patterns would be required at each site before an accurate determination of snow volumes and anticipated water yield can be derived. Given the relatively small volumes of extra water produced in Colorado, it is doubtful that these schemes would be envisioned to do much more than provide minor stability to late season streamflows or lake levels.

Within the sub-alpine forest region, watershed management research has been focused upon vegetation manipulation as a means

Figure 5.3a Probable Snow Management Sites in the Alpine Zone (as determined from Precipitation and Topographic Data in the Kananaskis District).



of increasing water yield. The premise supporting this research is that an increase in snow cover,hence water yield, is predictable in logged areas if information on precipitation, evapotranspiration, soils and wind patterns can be correlated with the size of the logged areas. In fact, the literature (Anderson, 1963; Wilm and Dunford, 1948; Hoover and Leaf, 1967; Packer, 1962; and Stanton 1968) shows the percentage increases in snowcover can range from 3 percent to 46 percent. Meiman (1968) summarized the effects of forest removal on snow accumulation by stating that "little real quantitative generalization is possible without an understanding of climatic and physiographic relationships". In fact, regional water yields are probably larger than normal due to past extensive fires. As forest growth continues the regional yield may decline.

In studies carried out on the Marmot Creek Experimental Watershed in the Kananaskis District, the same problem exists of explaining snow pack variations between cut and uncut blocks and the resultant water yield. In March 1978 this author participated in the snow surveys on Marmot Creek and in that year, as in previous years since the treatment blocks had been cut, statistically significant increases in snow water equivalent were recorded in the cut blocks as compared to the uncut control blocks. However, the control blocks also received as much snow as had been predicted, and the researchers were unable to explain the 22 percent increase in snow water equivalent in the cut blocks. The contribution from redistribution is not statistically valid, and explaining the gain as the recoup of former interception losses is no longer supported in the literature as it once was, yet no other explanation appears feasible. In any event, the ultimate goal of achieving a measureable water yield increase from this treatment was not forthcoming, until a re-evaluation of the data proved a 1 to 2 percent increase (Neill, 1980).

When compared to yield results obtained in Colorado and elsewhere, the results in Marmot Creek do not inspire confidence in the use of forest management for water yield increases. The study of forest treatment effects on snow pack and water yield conducted in northwestern Alberta at Hinton did provide a 27 percent increase in water yield or 187 mm versus 147 mm from the control sections, and this fact raises the question as to why similar results were not forthcoming from the Marmot Creek study. One possibility is the depletion of the snow pack through Chinook influxes that occur after the intensive snow survey in March. If Chinooks are part of the explanation for the poor water yield response to forest treatment, the extension of this form of water management to other parts of the Kananaskis District may prove unreliable for water supply augmentation. A second alternative is that only a small increase should be expected since the clearcuts represent a small portion of the basin. A third possibility is that the difference in percentage yield may be due to the difference in total precipitation from dry to wet years; however, the record has not been maintained long enough to verify this.

Obviously more research is needed to develop the exact nature and influence of the variations in total precipitation and of Chinook effects on snow in open and forested areas before a decision can be made regarding the usefulness of forest management for yield purposes. In the extreme case, Laycock (1973) has suggested that a 10 to 20 percent increase per unit area in water yield might be expected if much of the mature vegetative cover were removed due to changes in soil moisture utilization. In the Kananaskis District, given the limited amount of mature spruce timber left, the above estimates are probably optimistic. In fact, exploitation of the mature spruce forests in the Upper Kananaskis Valley, Smith-Dorien Creek and Marmot Creek areas might combine to contribute, given the precipitation characteristics of each area, an increase in total

basin yield of less than 24,670 dam^3 (20,000 acre-feet) in an average precipitation year and even less in a dry year when the yield increases would be most needed. Given the available information on forest management and water yield in general, it is not expected that this technique will be used to any great extent until more regionally appropriate information is available.

The possibility of utilizing structural alternatives to provide additional on-site storage for containing water from high runoff years for use in dry years, was investigated by TransAlta Utilities in 1972. Their findings were that opportunities for storage in the mountains were generally unavailable and that potential sites to be considered were to be found only along the Bow and possibly Elbow Rivers. Potential sites for small scale pumped storage developments at Upper Kananaskis Lake and in Ribbon Creek have been tentatively identified but have been shelved due to unfavourable cost development problems (TransAlta Utilities, pers. comm., 1980). Should the costs become less of a problem due to energy demands, or should downstream and on-site demands exert enough pressure for better control and maximum use of the water supply, the pumped storage schemes may reappear. The potential for water yield improvement in the Kananaskis District using snow or vegetation management techniques is small. It is estimated that a maximum 5 percent increase of the total average annual yield of 447,760 dam^3 (363,000 Ac.-ft.) could be made available in a normal precipitation year when the extra yield is not needed, however the amount would be less in a dry year. Given the unpredictability of air mass systems and unreliability of precipitation/vegetation relationships these options for improving water yield do not appear to be physically viable as alternatives in the near future.

As defined in Chapter 2.3.1 regime improvement implies a more seasonally equitable water supply. However, the natural flow regimen

from mountain streams generally peaks in the late spring-early summer and declines to a low winter base flow. The objective behind regime management is to delay the peak or diminish its volume so as to provide assured supplies in low flow periods.

Significant changes in the regime pattern have already taken place due to the storage developments and operational strategies of TransAlta Utilities. Before storage development, discharges below 9.2 cms (325 cfs) occurred more than 50 percent of the time, chiefly in the low-flow October-April period. After reservoir development these low discharges occur less frequently and are no longer characteristic of the winter season, but rather they dominate the post-runoff summer period of July-September as shown in Chapter 4.3. Similarly, extreme maximum flows have been muted by storage development, such that streamflows which used to exceed 28 cms (1000 cfs) about 20 percent of the time before development, now occur less than 5 percent of the time.

However, the present streamflow pattern as evidenced by the flow gauge above Pocaterra Creek and illustrated in Figures 4.3g and 4.3h clearly shows that on a seasonal and daily basis the patterns are not representative of an improved regime. In fact, when the present seasonal flow conditions are compared to the pre-development seasonal flow pattern, such as that depicted in Figure 4.3a, it is clear that a virtual reversal in seasonal regime has occured. Therefore, neither the natural flow system or the present strategy of flow management provide a seasonally equitable regime.

Regime management within the Kananaskis District may be accomplished using both structural or non-structural measures. In practice water yields are slightly decreasing and peak flows are

slightly diminished as the forest growth increases through policies of protection and fire suppression. As research has shown (Anderson 1967) a mature and dense vegetative cover helps trap snow, delay snowmelt and thus extend the runoff peak. Areas that were severely burned over during the disastrous fires of the 1930s and earlier, and areas that have been logged over are experiencing regrowth by variable aged stands of lodgepole pine which are increasing the amount of water consumed and lost by evapotranspiration. Coincident with the establishment of Kananaskis Country and Kananaskis Provincial Park, there is a renewed commitment to fire suppression and environmental protection (Alberta, Recreation and Parks, 1977). Thus water yield will continue to decline slightly as the dominantly young growth matures.

Another avenue of non-structural regime management utilizes modification of the natural forest cover in such a way as to enhance the desynchronization of the snowmelt runoff event. Research into forest management programs (Anderson, 1967; Hoover and Leaf, 1967; Meiman and Dietrich, 1975; Golding, 1977; Swanson and Hillman, 1977) has reported varying degrees of success with modifying snow accumulation and melt-rates. For the past several years, the Twin Creek sub-basin in the Marmot Creek Experimental Watershed has been the focus of a regime modification study. The treatment on Twin Creek is designed to prolong recession flow from snowmelt and to delay the time of peak runoff (Golding, 1977). Approximately 40 percent of the forested area in the sub-basin was cut into roughly 2500 circular openings about 12 m to 18 m (39 ft. to 59 ft.) in diameter or 3/4 to 1½ times the surrounding tree height. Preliminary results show increases up to 25 percent more snow water equivalent have been measured in the cut circles and that variable amounts of snow water equivalent remained in the cut circles after the snow pack has melted in the forest (Golding, 1977). Studies

are continuing in an effort to determine the exact nature of this delay on snowmelt on the stream hydrograph.

As far as non-structural measures are concerned then, regime improvement can be accomplished in the Kananaskis District in a minor way with forest fire protection, and may be supplemented by other forest management practices such as selective cutting for snowpack enhancement. Structural measures for achieving regime improvement could be developed using the existing storage system operating under a different strategy, the creation of new storage facilities or the addition of pumped storage schemes.

The present 209,700 dam^3 (170,000 ac-ft.) of storage within the Kananaskis District represents just under 47 percent of the average annual flow of the Kananaskis River and the upstream reservoirs comprise about 90 percent of this storage capacity. The strategy employed by TransAlta Utilities of utilizing the stored water for providing peaking power and peak load control in the winter period has resulted in the lake level and streamflow patterns described in Chapter 4.3 and 4.4. Given the ability of the storage facilities to adequately contain the spring runoff event, and in so doing completely change the natural regime pattern, it is clear that any flow and storage pattern between these two extremes can be effected by a change in operational strategy. Such a statement is not made to imply that a change is desirable, but merely to show that, if regime improvement is desired, it is within the realm of the present physical and structural capabilities of the District.

As part of an ongoing study into potential hydro development sites in the Bow River basin, TransAlta Utilities found that only 3 conventional sites on the Bow River would be suitable for additional development (Calgary Power, 1973). It was suggested at that time

that no additional development was planned since the potential storage sites identified are small in relation to present-day loads and generally lack storage potential. Some additional peaking capacity might be installed at some of the existing plants, or achieved by pumped storage developments utilizing relatively high heads between existing reservoirs (Calgary Power Ltd., 1973). Both the Upper Kananaskis Lake and Ribbon Creek areas in the Kananaskis District have been tentatively identified, although there is no commitment to develop either of these sites (Trans-Alta Utilities, pers. comm., 1982). Even if they were to be developed, it is obvious that their intended purpose would be to provide power. However, it is sufficient at this time to know that such developments are structurally feasible and physically practical (although currently uneconomic) and may one day be a factor in the dispensation of the regions water supply.

Potentially, regime improvement is a physically and structurally viable management alternative in the Kananaskis District. It is a naturally occurring phenomenon when the forest cover is encouraged to mature through a policy of fire protection and restricted cover removal. Because of major structural control of the watershed the seasonal regimen can be modified, given the bounds of the physical water supply patterns, to suit the needs of the user.

The potential for water quality management within the Kananaskis District will depend on the seasonal variations in the water supply and on the anticipated streamside recreational developments. Water chemistry measurements of several of the smaller streams within the Kananaskis basin show a relatively high alkalinity hardness and pH. However, nutrients are present in only very low concentrations and the presence of coliform and faecal coliform bacteria is rare (Alberta Environment, 1981). Values for suspended sediment, turbidity

total phosphorous and bacteria have higher than average concentrations during the high flow month of June. (Alberta Environment, 1981). It was also noted that major land clearing activities in the Evans-Thomas Creek area were responsible for extraordinarily high concentrations of suspended sediment (178 mg/l versus normal average of 3.4 mg/l) as early as March when local snowmelt runoff begins (Alberta Environment, 1981). The ability to limit peak flow responsible for erosion and sedimentation of water supply can be accomplished in part by regime management. The prevention or minimization of soil disturbance is aided by forest protection which we have seen helps to reduce peak flows and stabilize the soil mat of the forest floor. Construction activities including deforestation, associated with the development of current and planned recreational activities (ie. hiking trails, golf course, alpine villages, camp sites) are or will be responsible for erosion and sedimentation of streams. Proper site selection and the use of mitigation measures can reduce the locally produced and seasonally cyclical sedimentation problem. Regime management using structural control of streamflows can be used to reduce the peak seasonal and daily flows which are responsible for the higher than average concentrations of sediments, turbidity, phosphorous and bacteria.

Potentially water quality management is at present a viable objective and may become more so with anticipated near-shore developments. Present policies of protection of the forest and soil environment aid in regime improvement and help to minimize erosion and sedimentation. High flow periods have been associated with increases in sedimentation of streams through contributions by hillslope erosion and river bed scour. Control of the high flow periods using structural and non-structural measures offers alternatives for reducing sedimentation of the streams.

The potential for flood limitation management is tied in part to the balance between structural and non-structural alternatives and their influence on peak flow events. As discussed above, the encouragement of the growth of a mature forest cover helps to diminish the total water yield and delay the runoff event. Other measures for flood control, including zoning for use only those areas prone to flood damage, and restricting the activities of certain types of land use requiring an intensive infrastructure within high risk flood areas, are feasible. However, they may not be physically practical for obvious reasons. There are so few areas in the Kananaskis District that can accomodate the planned recreational facilities, that the lower valley areas will be the most intensively used for access roads, camp-sites, alpine villages and golf courses.

Reliance upon the reservoirs to provide flood control may be unwise since they do not have a large flood capacity, nor were they designed to operate as flood control reservoirs (TransAlta Utilities, pers. comm., 1982). Certainly the present level of storage is sufficient to handle the average year peak runoff event, but there has been some reservations expressed about the existing storage and flow capacity being able to handle the 798,000 dam^3 (646,940 ac-ft.) flood event of 1916 (Alberta Environment, pers. comm., 1982). No major floods or flood related problems have been experienced in the Kananaskis District since the present storage capacity has been in effect (TransAlta Utilities, pers. comm., 1982). However, this is due also to the lower yield climatic patterns characteristic of the post 1950's in addition to the operational strategy of the reservoirs.

Potentially, flood limitation management in the Kananaskis District can be exercised, with varying degrees of success, with three basic alternatives. Encouragement of a mature and dense forest cover will aid in minimizing peak runoff events. Reservoir storage may exist in some years after the usual volume of spring

runoff to accomodate further additions from snowmelt, rain on snow, or rain induced floods. However, the storage available would be insufficient to contain the volume of runoff such as that experienced in 1916. Finally, some measure of flood risk could be developed to identify areas where recreational and other forms of infrastructure would be subject to flood damage.

The potential for management of the stream and streamside environment is inextricably linked to the present and projected operational strategies of the water resource, in addition to the climatic and hydrologic patterns. The smaller, unregulated streams which are tributaries to the Kananaskis River, experience the majority of their streamflow in a few short weeks around the time of peak snowmelt runoff in late May and early June. Vegetation patterns are such that precipitation falling in the lower valley areas is generally used to replace soil moisture. There is little that can be done to improve the streamflow conditions of these streams short of massive snow management or water yield programs which remove large volumes of timber and streamside water-loving vegetation. However the problems associated with these measures may be more significant than the potential benefits.

The main stem of the Kananaskis River experiences extremes in flow throughout the summer and fall periods. Concerns have been expressed that these flow extremes are having a negative affect on certain aspects of the stream environment, particularly the sport fishing (Alberta, Recreation and Parks, pers. comm., 1982). The instantaneous flows required to support a broad range of stream environment needs including fisheries, wildlife, water-based recreational activities and aesthetics has been shown using the Tennant instream flow methodology. Given the same climatic conditions in the lower valley areas adjacent to the main river,

as described above, supplementation of the flows through some form of yield management or vegetation removal, would not likely provide either the stability or the volume of water necessary. The ability of the upstream structures to release known volumes of water at specified rates and times offers the best potential means of achieving the instream flows deemed desirable to improve the stream environment.

The major lakes experience large fluctuations in water levels due largely to the present water management policies. The huge drawdowns over the winter and spring period reveal large expanses of mud-flats dotted with rotting stumps. There is,given the current storage capacity,sufficient runoff from snowmelt to bring the levels up by late-summer or early fall. However, because of the colder climatic conditions above the lakes in early spring there is little potential of raising the lake levels faster than is now occuring using snow management or other non-structural techniques. Amending the operational strategy which determines the nature of flow releases from the lakes, would provide a greater potential for change to the water levels than any other means combined.

The choice of a regionally based water management objective will depend to a large extent on the ability of the region to accommodate it. Since the hydrology of the district has been significantly modified by structures, it is not surprising that both structural and non-structural measures may be useful in achieving certain objectives. However as noted in Chapter 1.1, some objectives may be more appropriate for particular watersheds due to the demands on the water resources of that basin, and while many objectives are complementary in combination, some are not.

As the supply and demand analysis of Chapter 5.2 has shown, there are several potential internal demands on the water supply and several significant demands on the water resources from external

sources. Given that there is the physical potential for the realization of regional objectives other than watershed protection, an assessment of the various alternatives in water management and how each conflicts or complements other uses and objectives follows.

5.3.2 Alternative Strategies in Water Management

To this point, the discussion has focussed on descriptions and analysis of the physical water supply patterns and the internal and external water demands. Significant changes have been made in the hydrology of the Kananaskis District, largely as a result of the demand orientations of TransAlta Utilities. As the water demands from other sectors increase, the potential for conflicts concerning the quantity, quality and timing of water supplies from the Kananaskis watershed increase. Some of these conflicts, both present and potential, are documented in published sources, while a great many others are alluded to in unpublished sources such as internal government reports. Still others have been developed using personal observations of watershed conditions, or communications with representatives in government (civic, provincial and federal) and industry. The synthesis of the water supply/demand relationships and assessment of the water management alternatives is the primary objective of this thesis.

The primary use of the waters of the Kananaskis District for much of the past 50 years has been to supply hydro-power for TransAlta Utilities. Although the primary use has not changed, the demand patterns have and this is reflected in the marked daily and seasonal changes in lake level and streamflow patterns described at length in Chapter 4.3 and 4.4. This single use management orientation has worked, more or less successfully, for the past several decades primarily because competing uses could make do with whatever

quantity of water was available whenever it was available. There are indications however that for the past few years and certainly in the near future the demands for water by the competing uses may increase to levels where conflicts in use may arise.

There are potentially contradictory objectives in water management when one compares statements in the Water Development Licenses, the policy statements for Recreation Development in Kananaskis Country and for Resource Management in the Eastern Slopes and the Irrigation Act. In the Water Development Licenses which govern the operation of each hydro facility or storage structure, there are no guidelines or requirements for minimum daily flows or water levels in the Kananaskis watershed (TransAlta Utilities, pers. comm., 1982). In the Irrigation Act however, the Minister of Environment is given authority to direct that streamflows be increased from the Bow River reservoirs, including the Kananaskis District, so as to preserve the legal rights established under the Act (Dybvig, 1979). In the Provincial policies on Recreation Development and Resource Management, the management objective is stated as being one of watershed protection, although it is not made clear how this objective can or should be applied to problem areas or situations (Alberta, Recreation and Parks, 1977; Alberta, Energy and Natural Resources, 1977). In addition to the above, there are also instream flow requirements in the Bow River which are covered by informal agreements between TransAlta Utilities and the Province of Alberta (Dybvig, 1979), and the Apportionment Agreement between the Province of Alberta and the Government of Canada, Saskatchewan and Manitoba, which guarantees that a minimum annual flow volume be passed downstream and that a minimum instantaneous boundary flow be maintained (Dybvig, 1979).

The ability to satisfy these obligations will depend on the

ability to balance the water demands at present and in the future with variations in water supply. The potential for changes in the water supply patterns by man or nature would also have an effect on the demand orientations, and ultimately the strategy of water management. The following discussion synthesizes the various water demand and supply configurations in an attempt to describe what the potential alternative strategies in water management are and how they might be developed. The most straightforward management scenario to deal with is the one which projects the present supply and demand trends to predict future results assuming existing policies are carried forward with no changes. Also, no alternatives to the present demand orientations are considered in this scenario so that conflicts in demand between uses will become apparent as soon as they occur.

It was suggested in the demand analysis that the Bow River Hydro plants would operate in the near future in a similar mode as at present. This is due to the forecasted 7.7 percent increase in net energy demand annually between 1980 and 1988, which represents an increase from 3700 MW in 1980 to 6650 MW in 1988 (Electric Utility Planning Council, 1981). During the same period the proportion of reserve generating capacity will decline from 30 percent of the installed capacity to 17 percent. Since the hydro operations are more flexible they will continue to handle the daily and winter seasonal peak energy demands, as well as a necessary proportion of potential energy reserve. For these reasons, it is suggested that the flow and lake level conditions in the Kananaskis and Bow River will continue to reflect these demands and the associated hydrologic conditions which have been described in detail in Chapter 2.2 and 5.2.

As a result, instream flow requirements in the Kananaskis River, for fisheries, habitat protection and environmental aesthetics

would suffer, often violating even the minimum flow levels and depths required during a normal flow year, as illustrated in Figure 5.2f. In the Bow River above Calgary the instream flow requirement of 39.65 cms (1400 cfs) was satisfied over 97 percent of the time between 1970 and 1979, even during the low flow year of 1977. However, in 1979 the flow in the Bow River measured at Calgary was similar to that of 1977 and the minimum flow level of 39.65 cms (1400 cfs) was violated over 20 percent of the time chiefly in the winter months of October through to December. With a continuation of TransAlta's storage policies, instream flow requirements in the Bow River above Calgary for fish habitat and water quality for human consumptive use would be satisfied in normal flow years, but would fail to meet the minimum levels required during low flow years up to 20 percent of the time.

The municipal and industrial demand for water from the Bow River by the City of Calgary amounted to 50,895 dam^3 (41,260 Ac-ft.) in 1979 (City of Calgary, pers. comm., 1982a). Over 11 percent of this total was taken in the month of July when flow in the Bow River totalled 276,000 dam^3. Therefore only 2.0 percent of the available flow in the Bow River was tapped for use by the City of Calgary in the high demand month of July. During the winter month of November 1979, only 4.5 percent of the total monthly discharge of 80,000 dam^3 (64,860 Ac-ft.) was diverted for use by the City of Calgary from the Bow River.

Neither of these statistics include the sanitary sewer return flows which have been measured to average as high as 90 percent of demand in the winter time and 60 percent of demand in the summer. They also do not include the contribution from the storm sewer system

which the previous discussion in Chapter 2.2.2 showed could amount to at least as much as the net consumptive use.

Forecasted annual demands for water from the Bow River by the City of Calgary (see Table 2.2c) will rise to surpass the contribution from the Glenmore Reservoir on the Elbow River in 1984. By 1988 the demand from the Bow River is forecast to increase to approximately 143,200 dam^3 (116,100 Ac-ft.) annually. This represents only 5 percent of the average annual flow in the Bow River as measured at Calgary and 6.8 percent of the dry year annual flow such as that measured in 1977. The far future demand forecast for the year 2001 of 249,900 dam^3 represents only 8.5 percent of the average annual flow and 12 percent of the dry year annual flow measured in 1977. Again, return flows to the Bow River from the sanitary and storm sewer systems are not included in the demand forecasts, so that actual consumptive use would be 60 to 90 percent less, and total combined returns might still exceed total consumption. The average peak month forecast demand in 1988 of 11.5 percent in July would account for 16,470 dam^3 (13,350 Ac-ft.) or only 6 percent of the flow during a dry year such as 1979. Even in the year 2001, the peak summer demand forecast in July of 28,740 dam^3 (23,300 Ac-ft.) represents 12.5 percent of the low flow volume of flow in July of 1977. Neither of these statistics contain any compensation for return flows. It is clearly evident that even during a dry year period, similar to that experienced in 1977 or 1979, the municipal demands for water under the existing water management strategy will not reduce flows in the Bow River to a level where instream flow requirements are threatened.

The major problem facing the water demand requirement of the City of Calgary is not a function of the availability of water

supply but rather a function of the capacity of the water delivery infrastructure at the Bearspaw Reservoir. Recent (1979) peak daily water demands have reached near capacity of the plant, prompting a expansion in 1982 costing $50 million and increasing plant capacity to 1364 million litres per day (300 million imperial gallons) from the existing 955 million litres per day (210 million imperial gallons). Gysi (1981) has argued that this expansion is strictly to serve the immediate and excessive peak daily demands of urban water users. This is largely true since the average daily demand for the city measured only 45 percent of the available capacity in 1979, and ideally the expansion should not be required for another 20 years.

The lack of metering and pricing control over water use in Calgary is responsible in part, for the excessive demands on water. Given a continuation of the flow patterns in the Bow River as determined by TransAlta Utilities, it is apparent that municipal water demands by the City of Calgary should not be affected by the availability of supply in the Bow River in a normal or dry year. However, the capability of the municipal delivery systems to satisfy peak demands is presently taxed due to the pricing structure and lack of metering, and even the current plant expansion will be taxed at the current rate of growth by the mid 1990s. Changes in the pricing structure would influence the rate of increase in municipal water demand, yet the overall effect on Bow River flows would be negligible well past the year 2001.

Instream flows below Calgary and at the provincial boundary with Saskatchewan have been affected by the present demand orientations

to such an extent that minimum standards for water quality and minimum flow requirements have suffered repeated violations. The discussion in the previous section (Chapter 5.2) has shown that several water chemistry parameters, including phenolics, oil, grease, bacteria and nutrients do not meet Alberta Surface Water Quality objectives in the river reach below Calgary. The source of these contaminants is largely the storm sewer system for the inorganics and the sanitary sewer system for the organics. The inorganic substances reach their highest concentration during the high runoff periods in the City in late March - early April and later in the summer from intense rainstorms particularly in August. The organics, although displaying high concentrations in the winter period, are most noticeable in summer due to their uptake by aquatic plants. Only during the high flow month of June is the concentration of phosphates and nitrates diluted to levels below the minimum provincial standards (Alberta Environment, 1981a). Current commitments by the City of Calgary to reduce phosphorous emissions from the sanitary sewer system may be successful. However, increases in runoff in the storm sewer system due to increases in impervious areas will contribute more phosphorous and other chemicals to the water supply of the Bow River with little or no treatment.

Major seasonal withdrawals near Carseland and Bassano have been responsible for reducing river flows below the recommended 42.5 cms (1500 cfs) limit required for instream needs under the current seasonal operation. In 1979, which was a dry year similar to that experienced in 1977, instream flow in the Bow River below Bassano was maintained below the recommended minimum from July 3rd to well past the end of October, actually staying below 7.0 cms (245 cfs) for a period of 2 weeks in mid-summer. In 1980, a normal flow year, withdrawals at Bassano were enough to decrease the daily

discharge to levels below 3.0 cms (105 cfs) for several days, and in addition, daily flows remained below the recommended levels from mid-July until mid-October.

Repeated withdrawals of water of the same magnitude or greater from the Bow River south of Calgary in a dry year such as those experienced in 1977 and 1979, will ensure that flow violations and associated reductions in water quality will occur. Even in normal flow years which follow dry years, a continuation in the present flow strategy with no increases in storage, will lead to flow violations such as that experienced in 1980.

Given the present management strategy of flow releases and the current water volumes in both average and dry flow years as measured at Calgary and Bassano, an estimate of the influence of irrigation demands on Bow River flows can be made. The current consumptive use for the Bow River basin irrigation districts of 5.09 dam^3/hectare (1.67 Ac-ft./Ac.) is assumed to hold true for future years (ie. no change in crop requirements). Also the rate of increase in growth of irrigable acreage is forecast to increase at the nominal levels of the 1975-1979 period, that is 4 percent per annum. The results of this forecast for water diversion and consumptive use versus available supply are shown in Figure 5.3b.

Several different flow scenarios for an average and dry year are used to provide a perspective of irrigation demand on Bow River flows. If no changes are made to supplement the yield in the Bow River basin, irrigable hectares increase at a constant nominal rate as described above and in Chapters 2.2 and 5.2, and unit consumptive uses remains static at 5.09 dam^3/hectare (1.67 Ac-ft./Ac), then the estimated diversion volume will reach the 50 percent level of mean annual flow in Calgary sometime around 1986. As is illustrated

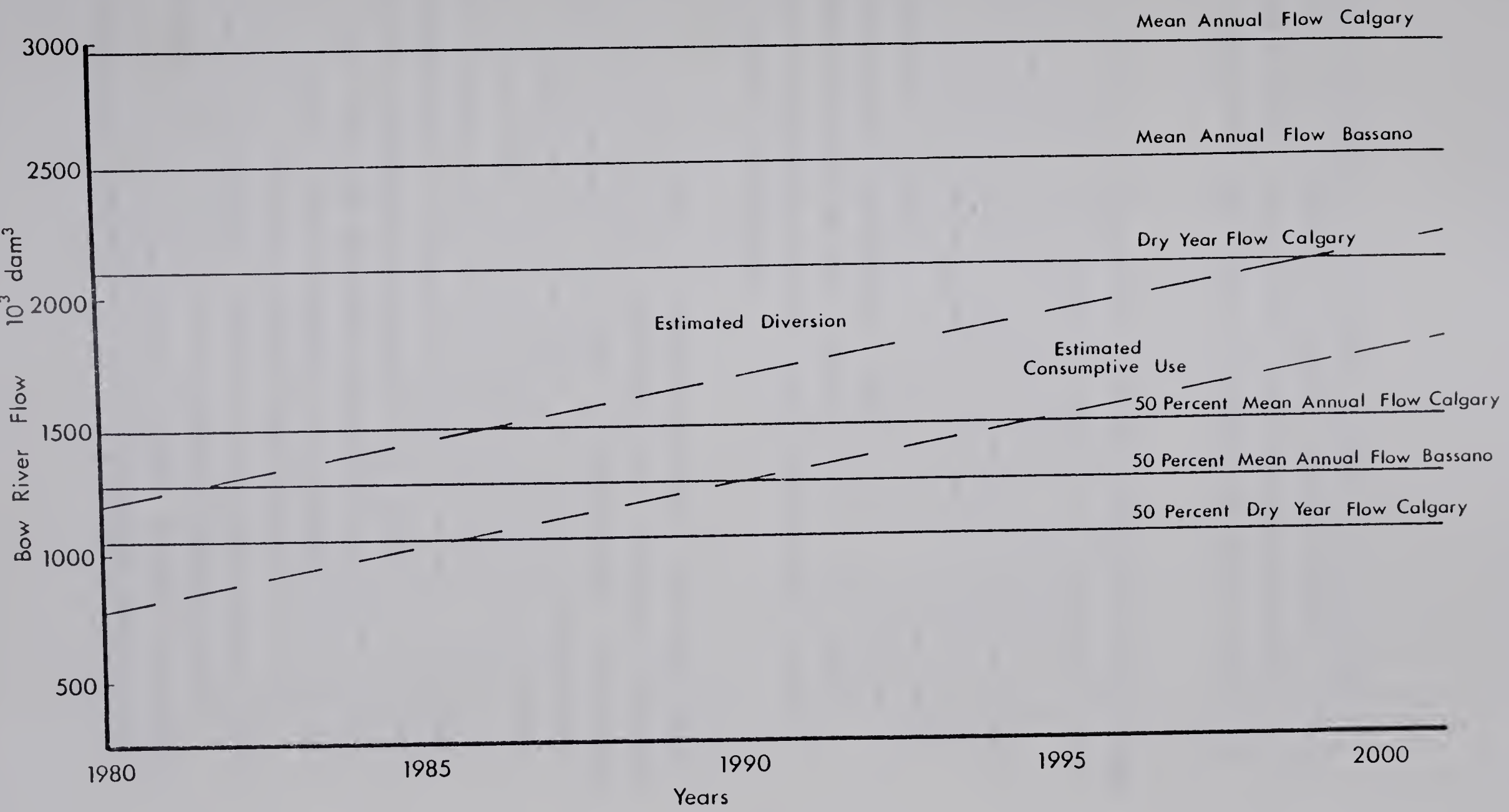


Figure 5.3b Estimated Water Diversion and Consumptive Use by Irrigation Districts in Bow River Basin.

for diversion purposes in the diagram, already more than half of the dry year flow as measured at Calgary has been exceeded. By the end of this century, the potential total diversion could well amount to more water than there is available in the Bow River in a dry year.

The estimated consumptive use line was developed using the same assumptions as above. The significant aspect of this graph is that by 1995, 50 percent of the mean annual flow of the Bow River as measured at Calgary would be required to satisfy irrigation demands. Even more telling is the requirement of 50 percent of the dry year flow as measured at Calgary by as early as 1986. In these latter cases, the required contribution to Apportionment is satisfied (if it is assumed that the Bow River contributes only 33%) although the actual flow remaining would be insufficient to meet instream flow requirements below Bassano.

Thus under the present management strategy of Bow River operations by TransAlta Utilities, and with no major changes in upstream storage and flow patterns, the volume of flow available for use will decline in average and dry flow years. The Bow River irrigation districts now use about 5.09 dam^3/hectare (1.67 Ac-ft./Ac.) and it is assumed that this will hold true for future years. With a nominal growth rate of 4 percent in irrigable hectares, estimates of demand and consumptive use indicate in an average or dry flow year that 1986 marks the year when 50 percent of the flow in the Bow River at Calgary will be required. In a normal flow year this demand should not impede the required contribution of Bow River flows to meet Apportionment. However in a dry year, such as 1977, consumptive use will account for a 50 percent reduction in the flows in the Bow River below Calgary in 1986. By 1995, at present rates of growth and consumptive use, the irrigation districts will

consume about 50 percent of the average annual flow in the Bow River as measured at Calgary. Unlike the 1986 example, the volume of consumptive use in 1996 may be sufficient to impede the required contribution by the Bow River to meet the Apportionment agreement and will certainly reduce instream flows below desirable levels for fish. Of course changes in use patterns or growth patterns would influence the demand curves, and these will be discussed further below. The present water demand versus supply arrangement is such that in an average flow year, the Apportionment agreement is easily satisfied on an annual volume basis. In a dry year though,demands for water are greater, particularly from the irrigation districts, and the amount of water available to pass downstream is less in proportion to consumptive losses.

Again, referring to Figure 5.3b, by 1995, consumptive use by the irrigation districts may have reached the point where 50 percent of the mean annual flow of the Bow River, as measured at Calgary is required. As a consequence, in a dry year such as that experienced in 1977, the flow remaining after the irrigation districts took their share in 1995 would approximate 600,000 dam^3 (486,400 Ac-ft.). This would mean that Bow River users were consuming in excess of 50 percent of the flow during a dry year, and contributing less than the required one-third flow to ensure even the minimum discharge of 2.6 million dam^3 (2.1 million Ac-ft.). Thus with continued nominal growth and unit usage rates, the ability of the Bow River to contribute its required portion of the Apportionment flow, would be greatly reduced in a dry year by the middle of the next decade.

Within the current policy of protection and with a continuation of the present water management strategy by TransAlta Utilities, several concerns are apparent at present and in the future. Instream flow requirements in the Kananaskis River for fisheries, habitat protection, water-based recreational activities and environmental

aesthetics, are presently and will, in the future, be insufficient to meet even the minimum water levels and flows needed in some years and particularly in dry years. Instream flow requirements above Calgary are complemented by the present strategy which supplements the low Bow River winter flows. In fact, without this supplementation during the winter season, the minimum flow requirement of 39.65 cms (1400 cfs) would be violated over most of the winter period in a normal dry year. The municipal demand of the City of Calgary from the Bow River amounts to between 2 and 6 percent per month of the mean monthly flow in any season. Since between 60 to 90 percent of this is returned on a monthly basis to the river from the sanitary sewer system and an additional 20 to 30 percent is supplied from the storm sewer system, no supply problems with the present flow strategy are foreseen at present or in the far future. However, the capacity of the municipal delivery system is inadequate to handle the peak demands and will require repeated regular increases unless conservational policies (ie. metering, user costing, etc.) are introduced. Water quality below Calgary is affected by the municipal demand in the form of sanitary and storm sewer discharges which, during especially the summer season, raise the concentration of organic and inorganic substances above the minimum levels specified by the Province of Alberta. High flows in June dilute the concentrations to acceptable levels, but lower flows in the spring and late summer contribute to the higher than desirable levels. With the present flow conditions and the expected increases in population, sewage production, and storm sewer runoff, the ability of the river to assimilate wastes and inorganics will decline and water quality violations, particularly in the late summer period will increase. Under the present management strategy, the Bow River basin irrigation districts will consume 50 percent of the dry year flow as measured at Calgary as early as 1986. Since only about 50 percent of the annual flow in the Bow River is available from May to August it is evident that there will be little left in the river below Bassano to satisfy other users and water quality requirements. By 1995, the irrigation districts will consume about half the flow during an

average flow year and this will reduce instream flows below Bassano and reduce the contribution by the Bow River to Apportionment. Because of the large withdrawals at Bassano and the seasonal hold-back in flow by TransAlta, instream flows are below the minimum requirements in both average and dry flow years in mid-summer and these will get worse in the future.

In summary, the present water management strategy complements external peak power needs, instream flow needs above Calgary, and to some extent the municipal demands of the City of Calgary by ensuring higher than normal flows in the low-flow winter period. However it conflicts with instream flow requirements for fisheries, recreation and aesthetics in the Kananaskis basin, instream flow requirements below Calgary in late summer, and irrigation needs in late summer.

Through this analysis we have identified three major problem areas which conflict with the existing water management strategy. In the Kananaskis District the present flow and lake level conditions fall short of the desirable minimum for fish and aquatic habitat, water-based recreation activities and aesthetics. Irrigation requirements for water in the late summer period are high, yet this is the time when TransAlta is filling its reservoirs, thereby holding back potential flows. As irrigation demands increase, more of the available supply south of Calgary is diverted and consumed further reducing instream flows in the stretch of the river south of Bassano below the desirable levels for quality maintenance. Return flows from the irrigation districts help to bring the instream flows back to near the minimum requirements at the mouth of the Bow River, but it is obvious that sections of the river below Bassano are suffering and will continue to suffer under the existing flow strategy and volume of withdrawals.

Before looking at how these conflicts might be affected under

a different management strategy it is important to see if alternatives exist to reduce the degree of conflict within the existing strategy. Within the Kananaskis District the instream flows required by fish and others as an aquatic habitat,or for water-based recreation, were developed for this study using the Tennant (1976) method. Refering back to Figure 5.2f, the contemporary mean daily flow of the Kananaskis River above Barrier Reservoir generally drops below the recommended level for good fish, aquatic and recreational activities in April and stays below until late August. The Tennant requirement of instantaneous minimum flows is often not satisfied, even during days when the average flow levels are above the recommended limits, simply because of the variability of peaking flow over a 24 or 48 hour time period. In some months the present flow strategy failed completely to meet even the minimum flows recommended for fish survival or for a viable aquatic habitat for other users. Although a different instream flow methodology might recommend slightly different flow levels, there is little doubt that the present flow strategy of variable releases is incompatible with any sustained flow guideline. There is therefore no practical way of altering the instream flow needs to meet the existing water management strategy.

The problem with instream flow violations below Calgary and irrigation demands is that the former is directly affected by the latter, even though the initial volume of flow is determined in part from upstream reservoirs. As irrigation demands increase and diversions above Bassano grow larger, the amount of flow remaining declines often below the recommended flow level for quality maintenance. Additional supplies from upstream during the peak irrigation period would allow for increased diversions and less chance of violating the instream flow requirement below Bassano. However, this would require a fundamental change in the strategy of reservoir operations. Additional supplies for instream flow maintenance could also be had if the irrigation districts diverted less water. Gysi (1981)

has implied that irrigation demands are in excess of real needs because of low overall project efficiencies. Also, since the cost of water represents such a low proportion of total production costs (1.2 to 4.6 percent) depending on crop type, a considerable change in the price of water would have to occur before much change in irrigation demand could be observed. Real efforts can be made towards reducing the losses in the delivery and application systems, and thereby improving the level of efficiency from 33 percent of the water diverted. Many users in irrigation districts are moving to the use of pivot and other sprinkler systems as an alternative to the various forms of flood irrigation. Indeed, as many new sections are brought into production, the gravity-flood principles are no longer feasible. Upgrading of the delivery ditches in concrete, or in some cases buried pipe, has been undertaken in some districts to help reduce losses due to seepage and evaporation. An estimated doubling of the level of irrigation efficiency through just these improvements, could provide a significant volume of water for use in irrigation which is presently lost. With a 70 percent level of efficiency the total diversion for irrigation could be reduced by the year 2000 to about the same volume that was diverted in 1980, even with nominal annual increases in irrigable hectares of 4 percent per year. Such an improvement would release more water for instream flows below Bassano, thereby reducing the number and degree of flow violations, and in turn help to satisfy the Apportionment agreement. Any improvement in efficiency which stretches the available water supply would be philosophically in support of the provincial governments stated principle that the fullest utilization be made of the water resources in a basin before any consideration be given to inter-basin transfers.

Of the three major conflicts identified under the present water management strategy, even the minimum instream flow requirements within the Kananaskis District remain unsatisfied. Viable alternatives do exist within the irrigation infrastructure to be able to cope with the present system, but only if continued improvements in

efficiency are realized. With improvements in efficiency of delivery and application systems additional flows are available to supplement in the instream flows below Bassano and help alleviate the water quality concerns in that stretch of the river.

An alternate management scenario to the one discussed above would be one that placed a greater emphasis on increasing the total water supply available for all uses. There is some justification for examining the feasibility of water yield management, since it had been the stated objective of the Eastern Rockies Forest Conservation Board, and was the stimulus of much of the research carried out by the Alberta (East Slopes) Watershed Research Program. Also the need or demand for more water for municipal and irrigation requirements has been advocated or refuted in several papers, symposia and conference proceedings (see especially: Smith, 1977; Gysi, 1981). In the Kananaskis District and Bow River Basin, studies by TransAlta Utilities into finding ways of increasing hydro-power production have focussed on diversions, storage increases or pumped storage schemes (Calgary Power Ltd., 1973). Most diversions such as Kent Creek, French Creek and Burstall Creek were built to optimize power production but involved small volumes of water. Any further additions or increases in storage have been largely rejected due to available sites having a lack of sufficient capacity to justify the cost, and pumped storage schemes, particularly at the Kananaskis Lakes, were also rejected because of poor cost-benefit statistics (Calgary Power Ltd., 1973). Since the bulk of the present reservoir storage is used in the winter period to satisfy seasonal peak power demands and the existing capacity is satisfied by existing runoff volumes, additional increases in runoff produced from diversions or storage from wet to dry years would be in excess of present internal hydro-power storage and generation capabilities.

Increases in water yield in the Kananaskis District from non-structural measures such as vegetation management or high elevation

snowpack management were discussed in the previous section. The physical potential for each is considered small (less than 5 percent of total basin runoff) due to the limited areal extent of merchantable, mature timber for cutting, and also due to the relatively few areally extensive high elevation areas conducive to snow management. In addition there is no assurance, given the current orientation of land use protection and preservation advocated in the policies for Recreation Development (Alberta, Recreation and Parks, 1977) and Resource Management (Alberta, Energy and Natural Resources, 1977), that any changes in vegetation structure or land use would be allowed. Any naturally produced increases in water yield would, without any increases in storage, supplement the peak runoff event contributing to higher flows in June and perhaps a slightly extended flow recession in July. These flow conditions are still not ideal for instream uses due to their large range and ultimately, since the strategy of reservoir operation would not have changed, flow releases in much of the summer recreational period would continue to be insufficient or highly unstable. Since the objective of yield improvement does not address the problem of unstable instream flow conditions, it would not represent a more viable or desirable alternative to the present strategy.

On the surface, the external demand for increased water yield would appear valid given the increasing demands by the irrigation districts for water, and the subsequent effects on instream flows below Bassano. The range of options for improving yield would include both non-structural and structural measures. Non-structural measures for increasing water yield might include vegetation and snow pack management, conservation or restriction of present uses, or changes in policy regarding flow obligations from the basin. The potential for successful yield increases in the Eastern Slopes has been reviewed in Chapter 2.1. Laycock (1973) suggested that as much as 20 percent more flow could be obtained if all the vegetation were removed. However, severe problems with erosion and sedimentation of the water supply would adversely influence water quality,

and flow timing would be flashy and unreliable. Opportunities for either form of yield management might ultimately be limited by the conservation and protection policies in effect over large parts of the Bow River headwaters by both the Federal and Provincial Governments. Conservation policies in the form of higher prices for water in municipal and irrigation sectors would have the effect of reducing demands, ensuring more water for instream flows. Gysi (1981) has discussed the effect of price elasticity and suggests that if higher prices were charged for irrigation water there would be a careful re-ordering of priorities regarding production and methods of operation.

At present, each river contributing to the South Saskatchewan operates under a constraint to allow at least half the flow originating in that river basin, or the one-third minimum necessary to satisfy the 2.6 million dam^3 (2.1 million Ac-ft.) to meet the Apportionment Agreement. Owing to a higher population and more intensive irrigation, the demands on the water supply of the Bow and Oldman Rivers exceed that in the Red Deer Basin. More of the Apportionment requirement could be taken up by the Red Deer River to allow Bow River users to use more water. But this alternative is fraught with problems, not the least of which might be the objections of Red Deer basin residents to helping Bow River residents to benefit from extra supplies of water at the Red Deer basin's expense. Since the Apportionment Agreement does not disallow this practice, it certainly exists as a viable alternative to increase access to more water within the Bow River basin without physically changing the hydrology of the basin. The structural options would include storage reservoirs and/or interbasin transfers. As noted above, a study of potential sites for storage found only a few with any potential in the Bow River basin, but problems with costs and conflicts with adjacent land uses rendered these sites of little use under present conditions. In theory, interbasin transfers offer

the most secure and quantifiable means of increasing water supply. The transfer of water from northward flowing rivers has been discussed in Alberta before, the PRIME project of the late 1960s is a good example. Most recently (1980) a Conference on Interbasin Transfers was held in Edmonton, Aberta to discuss the theoretical and practical aspects of transfers. It has been and still remains the policy of the present Provincial Government that the full use of a basin's water must occur before any interbasin transfers will be considered. In the Bow River basin this would imply that only when the available water supply fails to satisfy all existing uses or agreements could augmentation of supply be considered. In a dry year like 1977, flow in the Bow River was about 75 percent of normal and combined consumptive uses totalled approximately 1,025,000 dam^3 (830,970 Ac-ft.). This represents about 43 percent of the natural dry year flow, and the majority of it was consumed by the irrigation districts. With present rates of growth and consumptive use patterns (see Figure 5.3b), the 50 percent level of flow in a dry year such as 1977 would be reached as early as 1992. Even in an average flow year, the maximum level of consumptive use allowed without violating the Apportionment Agreement would be reached, with a continuation of present demand patterns, as early as 1996. This suggests that Bow River basin residents might be justified in requesting augmentation of supply by 1992 and certainly by 1996.

However, several factors can influence the legitimacy of any such claim and some of these alternatives have been discussed earlier. Improvements in irrigation efficiency to twice the present levels would ensure sufficient water for use, even with nominal increases in irrigation hectares and consumption, during a dry year flow until approximately the year 2010. Increasing the costs of water would encourage conservation of supply and better user orientations but this can be very much offset by political or economic interferences through subsidies, restricted markets, fixed prices for products, etc. As Gysi (1981) would argue, because of low efficiencies in

water use by the irrigation districts, and high peak daily municipal demands fostered by wasteful pricing policies, the actual needs are much less than current demands would indicate. The real concern here is that without a thorough analysis of actual water needs and consideration of the range in alternatives for achieving these needs, a strong case for interbasin transfers could be made for the early 1990's, a full 20 years ahead of when it should be if efficiencies of use are encouraged and the government's principles of water management in Alberta are adhered to.

Ultimately the potential for yield improvement in the Kananaskis District is small, and the internal demands, particularly for better regulation of instream flows, are not satisfied by yield management within the District. Externally, non-structural measures for flow augmentation using vegetation or snow management in the high precipitation upper basin areas have little chance for use because of present restrictive land use policies which encourage environmental protection. Other non-structural measures such as changing pricing policies to discourage waste, and improvements in user efficiencies in municipal and irrigation sectors, would release extra volumes of water for other uses, particularly instream flow and Apportionment requirements. Structural alternatives for storing wet year flows for use in a dry year were found to be non cost-effective in 1973, and little discussion of this in the Bow River basin has taken place since. Interbasin transfers offer potentially the largest source of water for augmentation, but the actual needs do not appear to be as immediate as present demand patterns would first indicate. It is obvious that without a change in the demand orientations of downstream users, particularly the irrigation districts, interbasin transfers could become a very real alternative for water flow augmentation as early as the mid 1990's. While any form of yield increase would be welcome by the irrigation districts, and would be of use in alleviating instream flow concerns below Bassano, yield

improvement does not address the problem of instream flow violations in the Kananaskis District.

Another alternate management scenario would be one that placed a greater emphasis on improving the regime characteristics of streamflow and lake levels. Within the Kananaskis District, significant changes in the natural regime have occured, more because of the operational strategies of TransAlta Utilities than because of the structural changes in storage and channel diversions. The present regime for lake levels and streamflows has been fully discussed in Chapters 2.2.2 and 5.2.1, and the expectation for the continuation of this regime has been elaborated upon earlier in this chapter. Officially, government policy (Alberta, Recreation and Parks, 1977) recognizes that the Kananaskis reservoirs will continue to be operated for hydroelectric purposes, however there is no mention as to the strategy to be employed. Unofficially, internal government reports have questioned the effects of existing peaking operations on the sport fishing and other water-based recreational activities (Alberta, Energy and Natural Resources, 1980) and these concerns have been given credence through personal communications with internal sources (Alberta, Energy and Natural Resources, pers. comm., 1982). However, no alternative strategies have yet been developed by the provincial government, or at least proposed publicly, to be considered for implementation. Since the Recreation policy advocates sport fishing and several other recreational activities which have some association with water, there will be significant contact between recreational users and the water resources of the Kananaskis District. That the existing flow conditons are non-ideal for fish and aquatic habitat and recreational users, the very uses which are promoted in the policy, is clearly shown in Figure 5.2f. Increasing contact by recreational users will increase the probability of conflict between the Province of Alberta's desire for an environmentally and recreationally functional hydrologic system, and TransAlta Utilities rigid control of storage and stream-

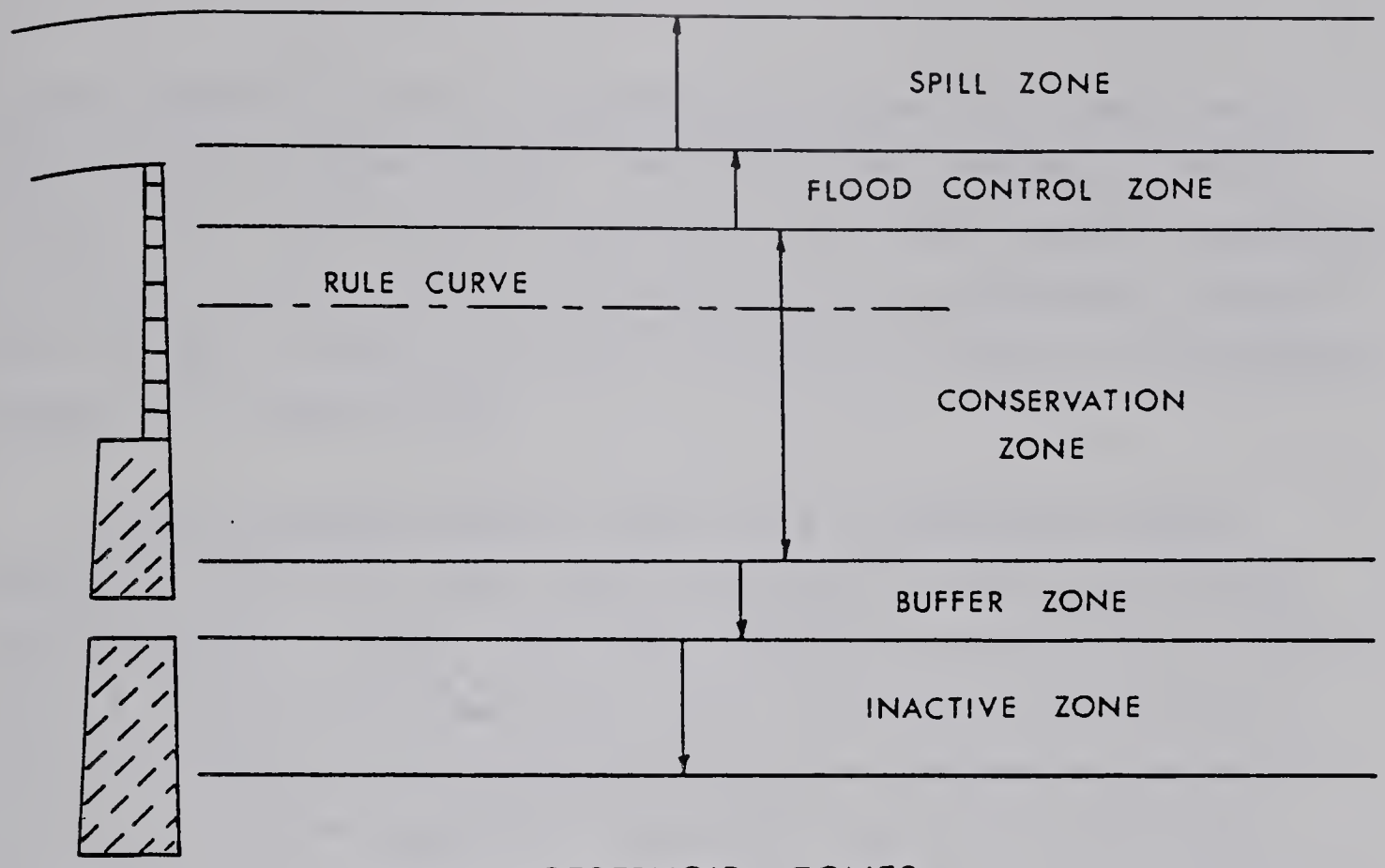
flow for peaking and winter season load assistance. If the Province of Alberta is serious about offering the water-based recreational opportunities that are proposed for the Kananaskis District, then some form of change in water management strategy is required.

From Figure 5.2e and 5.2f we can see that the historical and comtemporary regime conditions in the Kananaskis River below Lower Kananaskis Lake are diametrically opposed in time. Whereas in the pre-development and initial development stages of reservoir construction the natural flow system satisfied instream flow requirements in 10 out of 12 months, in the contemporary period of flow regulation instream flow requirements are seldom satisfied during the high use summer months. Potentially, a strategy to provide regime improvement within the District could stem fromstructural or non-structural measures. As the discussion in the previous section has shown, present land use policies advocating fire prevention assist in regime improvement by encouraging the development of a mature forest cover which in turn provides for delayed snowmelt, better percolation to groundwater, and slower release to streams, thus delaying the runoff peak. However, the nature of the problem in the Kananaskis District requires that a timely distribution of water be made available during the summer season in the immediate future, and this degree of control is beyond the scope of potential forest management programs. Since the operation of the reservoirs is ultimately the problem behind instream flow violations, these same structures offer the best avenue for a solution.

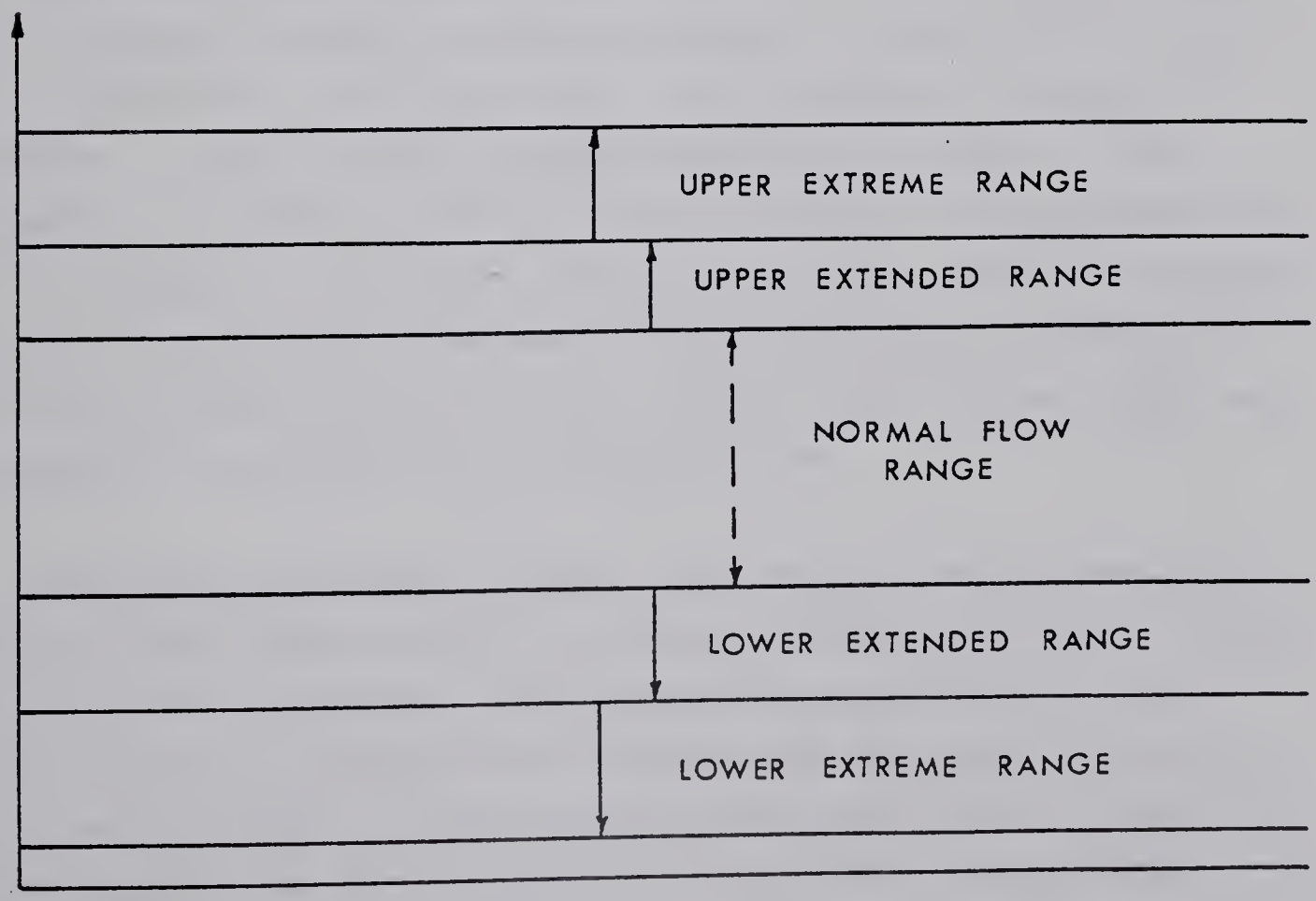
The development of a strategy for regime improvement requires a definition of the flow and water levels desired, and a scheme for effecting a change from current strategy. The need to define instream flow requirements elsewhere has resulted in the development of several methodologies. The methodology used as an example in

this study has apportioned the natural flow to provide the requisite flows and levels needed to sustain fish, wildlife and other aquatic users including water-based recreationists, while at the same time satisfying streamside aesthetics. In the Kananaskis River, at least 6.5 cms (230 cfs) is recommended as the mean daily instantaneous flow to support instream flow requirements for good fisheries habitat conditions during the months April through September. As an extreme minimum, it is recommended that no less than 0.8 cms (28 cfs) of flow be allowed since this would have potentially serious environmental and recreation repercusions. In essence, three distinct flow zones have been created by the Tennant method: those above the 40/20 seasonal split which provide optimal hydrologic conditions, those between the 40/20 seasonal split and 0.8 cms (28 cfs) which provides for moderately acceptable hydrologic conditions, and those below 0.8 cms (28 cfs) which defines unacceptably poor conditions for instream flow uses.

The concept of zoning was first introduced in water management studies as an aid in defining storage and flow criteria and in linking upstream storage and downstream flows (Sigvaldson, 1975) and it has been successfully applied in basins where there are conflicting demands for water (Sneyd, 1976). Establishing channel flow as being dependent on the zonal conditions of an upstream reservoir ensures a more balanced regime such that neither the reservoirs or river are managed at the expense of the other. A typical representation of the zoning relationship between lakes and streams is depicted in Figure 5.3c. The spill zone represents uncontrollable storage, while the flood control zone is capable of handling the excess between outlet and sill level. The conservation zone is defined as the zone within which most water-based demands are satisfied. A time dependent rule curve is added



RESERVOIR ZONES



CHANNEL FLOW ZONES

Figure 5.3c Zoning Relationships of Reservoirs and Channels

Source: Sneyd, 1976.

to the conservation zone to specifically delimit the ideal levels for a particular time period. The buffer zone represents reserve storage that would only be entered for water under abnormal conditions. The inactive zone is generally considered to be physically inaccessable storage; however, it could be defined for social or environmental reasons at a higher level.

In the Kananaskis River, flows would be maintained within prescribed upper and lower bounds depending on current lake levels and anticipated inflows. The lower extreme flow range might comprise the 0.8 cms (28 cfs) Tennant flow zone, a highly undesirable flow range for fisheries and aquatic habitat, and water-based recreational uses. The lower extended range might comprise the moderately acceptable flow range between 0.8 cms (28 cfs) and 6.5 cms (230 cfs). The normal flow range is synonomous with the 40 to 60 percent range of the average flow which represents between 6.5 cms (230 cfs) and 9.2 cms (323 cfs). This flow range would satisfy the Tennant requiremdnts for good to outstanding conditions for fisheries and recreation. The upper extended flow range would comprise between 60 and 100 percent of the natural average daily flow, providing optimal conditions for instream flow uses. Flows exceeding 100 percent of the natural average daily flow fall into the upper extreme range and are generally considered to be flushing flows.

This flow and storage strategy would require the reservoirs to be held at much higher levels in the early spring, and remain consistantly high over the summer, declining during the fall and early winter periods as contributions to downstream flows and declines in inflow reduce storage. This strategy would also limit or reduce the erratic daily flows characteristic of the last few summers highlighted in Figure 4.3h in Chapter 4.3. Such a strategy would, in effect, satisfy the instream flow requirements for fisheries and

aquatic habitat, and for water-based recreational users during the high activity summer period.

Once the strategy of regime management through structural control is accepted as feasible, there is need for a scheme to effect a change from the current strategy of TransAlta Utilities. One might assume that TransAlta Utilities would not voluntarily change their strategy of operation unless there were economic or political inducements to do so. Presumably, any reduction in reservoir storage during the winter season would reduce the potential energy reserve that TransAlta can count on during the high energy winter period. Similarly, regime management would eliminate the use of the river system for peaking operations, causing TransAlta to look elsewhere to satisfy the peak daily energy demands. It should be remembered that no loss of generating income need occur since the hydro plants can be operated as run-of-river plants, producing a steady seasonal base load. However, TransAlta may choose to produce the peaking power from other hydro installations thereby affecting the storage and flow balance of another river system. Another alternative would be to produce the necessary peaking power from coal or natural gas-fired thermal power stations, although these options are less flexible, introduce extra costs for fuels, and are non-renewable resources.

There are other inducements, both economic and political, which the provincial government might offer TransAlta Utilities as a tradeoff and some of these were mentioned in Chapter 5.2.2. Part of the 165 MW generation capacity of the Brazeau/Bighorn complex could be approved for use if the province and/or company undertook some floodplain management downstream so as to minimize the potential for flooding from ice jams. Even the utilization of one-quarter of this total would more than cover the entire contribution of the Kananaskis power plants. However, the current peaking practices of

TransAlta Utilities on the North Saskatchewan River have come under fire from the Environment Council of Alberta (Wierenga, 1982) and it is unlikely that further increases in peaking would be welcomed by this group. The province has ignored the advice of its advisory group in the past (ie. Paddle River, Red Deer River) and could do so in the future. It is unlikely that TransAlta Utilities would consider a policy it knows might potentially cause flood damage downstream since it has repeatedly asked the provincial government for help in identifying floodplain requirements downstream of the dams (Wierenga, 1982). With proper floodplain measures, the utilization of some of the currently unused generating capacity at the Brazeau/Bighorn would be more than sufficient to replace any lost peaking capacity.

As mentioned in Chapter 5.2.2, TransAlta Utilities has studied the feasibility of potential hydro sites on the Peace and Slave Rivers. Although construction, if approved, is not slated until the end of this century, the combined 2500 MW of generation will provide additional base load power for the provincial interconnected grid. Further development of the Peace River might face considerable opposition from environmental groups who vigorously opposed the W.A.C. Bennett dam when it was built due to anticipated changes of the local and downstream fluvial systems. Similarly, the Mountain Rapids site is located adjacent to Wood Buffalo National Park, and as such will involve negotiations with federal and provincial government agencies. The provincial government could aid the company's applications for development by providing base line environmental studies, and assist in negotiations with the federal government in return for concessions in the operations of the Kananaskis hydro plants.

The provincial government ultimately has control of the water resources of the province and through the Water Resources Act dispenses licenses for users. Although the development licenses

covering the Kananaskis hydro plants have no flow regulations, the provincial government, through the Minister of Environment, can specify flow rates from the Bow River reservoirs over those desired by TransAlta Utilities. Potentially regime improvement could be achieved through Ministerial actions or through changes in licensing constraints without prior agreement by TransAlta Utilities. There is no evidence of public pressure on the government to follow such a course of action. Yet concerns have been expressed (Alberta, Energy and Natural Resources, pers. comm., 1982) that changes, with or without the compliance of TransAlta Utilities, are needed to provide the hydrologic conditions necessary to support the goals of the existing land use policies.

Given that regime management is structurally viable and politically feasible, the change in timing and amount of flow releases will have some effect on downstream users. The regime management practices in the Kananaskis District would increase flow levels in the Bow River during the summer period, as is evident from Figure 5.2h. The actual volumetric increase in flow would depend on the type of year it is climatically and on available storage from the previous year. It is apparent from previous years flow records that increases in May could range up to 610 percent or 4.54 cms (160 cfs) higher than contemporary flows. In an average year, the mean monthly flow addition during the four summer months from this strategy could amount to between 3.5 cms (125 cfs) and 5.8 cms (205 cfs). The estimated total amount of water additionally made available during this period would approximate 60,000 dam^3 (48,600 Ac-ft.), up 250 percent from the average annual contemporary volume of 24,000 dam^3 (19,500 Ac-ft.).

Instream flow requirements above Calgary are generally satisfied under the present management strategy, since the contributions from upstream reservoirs and natural runoff are seasonally sufficient. Any reductions in winter flows due to regime management in the

Kananaskis District, are more than compensated for by the normal winter contributions from the upstream reservoirs.

The major municipal and industrial demands by the City of Calgary occur during the summer months as shown in Chapter 2.2 and Table 2.2d. From this Table and the discussion in Chapter 5.2, almost 50 percent of the consumptive use by the City of Calgary takes place during the summer months of June through August. This is also the period of peak flow in the Bow River, and the marginal consumptive use by the City of Calgary at this time is easily complemented under the present management strategy and under a strategy of regime management. The slight reduction to Bow River flows in the winter period is more than compensated for by a reduction in the municipal consumptive use by almost 80 percent. Since the actual total municipal demand is small in comparison to the average year flow, representing about 2 percent of the flow as measured at Calgary, the availability of flow for municipal purposes is more than sufficient under a strategy of regime improvement.

Instream flows below Calgary during the May through October period have been, in the dry years of 1977 and 1979 and even in an average flow year such as 1980, insufficient to satisfy the provincial flow requirement of 39.6 cms (1400 cfs). One consequence of these low flows has been an increase in the concentration of organic and inorganic pollutants above the allowable limits as determined by the provincial water quality guidelines. Supplementation of the Bow River flows by the additions from regime management in the Kananaskis District will only help maintain the instream flow requirements on days where the flow violation is within 3 to 5 cms (106 to 176 cfs). On several occasions in the summer of 1980, streamflow measured at Bassano was less than 4 cms (141 cfs) and the small amount of increase from regime improvement would be of little help in satisfying flow requirements or quality concerns under these circumstances. Although any flow increase during the

summer period would be welcome, the obvious solution to the instream flow quality problem, would be to reduce the volume of effluent introduced into the river at Calgary, and similarly reduce the volume of diversions by the irrigation districts at Bassano. Thus, regime improvement in the Kananaskis District can provide the flow supplementation below Calgary required to alleviate minor flow violations during the summer months. However, it is not the solution to the problems of massive flow violations and subsequent water quality violations.

The estimated additional 60,000 dam^3 (48,600 Ac-ft) flow available during the summer from regime improvement in the Kananaskis District represents about 5 percent of the total 1980 withdrawal by the Bow River irrigation Districts. At current rates of irrigation expansion and consumptive use the additional water supply would irrigate approximately 11,000 hectares and would be consumed by 1982. Although the increased summer flow from regime management complements the seasonal demand requirements of the irrigation districts, the sheer volume of present diversion and consumptive uses overshadows the additional contribution from the Kananaskis District. Without any improvement in use efficiencies from present levels, the extra supplies would be readily consumed and little additional instream flow assistance below Bassano would be evident.

The effect of regime improvement in the Kananaskis District on the flow and Apportionment constraints at the provincial boundary with Saskatchewan will be to reduce the flow quantities in the fall-winter season and accentuate even further the existing temporal disparity. Traditionally flows in the South Saskatchewan River during the summer are supplemented by return flows from the irrigation districts and the boundary flow requirements of 42.5 cms (1500 cfs) is satisfied, even during dry years in the early summer period. Most recently (1979-80) boundary flow violations have occured

in late-fall and mid-winter and the reduction of approximately 5 percent of the fall-winter-spring flow due to regime improvement implies that further flow violations will occur, and thus the upstream regime strategy is in conflict with the boundary flow requirement.

The above discussion does not even take into consideration that the irrigation districts might very well take much of the increase during the summer demand period. With only a temporal redistribution of flow, the Apportionment Agreement is satisfied and will continue to be satisfied until the end of this decade if it is assumed that the Bow River Basin contributes only 33 percent towards satisfying this Agreement. In a dry year, the Bow River could fail to meet the Apportionment contribution of 33 percent, given a continuation of existing growth and water usage trends, as early as 1986. So regime improvement in the Kananaskis District could result in boundary flow violations in the fall-winter season and if present use orientations continue, could also result in less water available for satisfying the Bow River portion of the Apportionment Agreement in a dry year as early as the middle of this decade.

The establishment of regime improvement as the watershed management objective in the Kananaskis District would have wide-reaching ramifications internally and externally. Present land use policies for protection of forests are indirectly improving the natural regime; however, major changes in the temporal distibution of lake levels and streamflows can only be effected by using structural measures. The instream flow methodology used as an example in this study provides the basis for apportioning sufficient flows in the summer months to support fish, aquatic habitat and water-based recreational uses, and thereby provides a more balanced seasonal regime. The storage and streamflow strategy of regime management is in direct conflict with the present peaking strategy of TransAlta Utilities, although several alternatives or potential tradeoffs are available. The feasibility of actually effecting a change in

strategy will depend on the political and economic climate in the province of Alberta, and on the attractiveness of alternative options for TransAlta Utilities. There is no major conflict between instream flow requirements above Calgary and regime management in the Kananaskis District since the contributions from upstream reservoirs in winter and natural runoff in summer are sufficient to satisfy the 39.6 cms (1400 cfs) flow constraint. The municipal and industrial demands for water by the City of Calgary are complemented in the high summer demand period by the redistributed flow from regime management. The current extraction of approximately 2 percent of the average Bow River flow as measured at Calgary should not be a source of major concern with respect to municipal water supply. However, even this demand is excessive since there are inadequate cost, conservation and accountability measures in the City of Calgary governing water use. Current fiscal expenditures for expanded municipal delivery systems are in response to ensuring fulfillment of excessive peak daily demands and are not affected by regime management in the Kananaskis District. Instream flow requirements below Calgary will be complemented by regime management in the Kananaskis District since the redistributed flow will provide extra flows in the summer period when streamflow is traditionally at its lowest level due to irrigation withdrawls. The extra flow will not eliminate the flow violations and subsequent water quality problems, but may ameliorate those days when only minor supplementation is required to maintain the 39.6 cms (1400 cfs) flow constraint. Of course, any potential benefit to instream flows below Calgary is dependent on the demands of the irrigation districts, because at current rates of growth in irrigable hectares and consumptive use the irrigation districts could conceivably use all of the additional flow by 1982 (based on 1980 growth and consumptive use statistics.) Regime improvement complements the irrigation demand by redistributing water from the fall-winter period into the summer period. The additional flow would be small, less than 5 percent of

present (1980) demand requirements, and without any provision for storage (preferrably offstream) would be diverted for use by 1982. Regime improvement in the Kananaskis District would reduce flow in the fall-winter-spring period violating further the boundary flow requirement of 42.5 cms (1500 cfs) during this period. It could also result in less water available for satisfying the one-third contribution of the Bow River to the Apportionment agreement in a dry year before the end of this decade.

We have seen in Chapter 5.3.1 that present and potential concerns of water quality management in the Kananaskis District are dependent on the seasonal variations in water supply and on anticipated streamside recreational developments. The ability to limit peak flows within and between seasons which are responsible for erosion and sedimentation of the water supply can be accomplished in part by regime management. Water chemistry analysis shows a very low concentration of nutrients and bacteria and with planned recreational developments, proper sanitation measures will be required to maintain these elements below acceptable limits. The increased flow attributed to regime improvement during the high use summer period will help dilute the concentration of nutrients and bacteria released from sanitary systems. Present policies of protection of the forest and soil environment aid in regime improvement and help minimize erosion and the subsequent deterioration in water quality. Therefore the objective of water quality management is complementary with regime improvement in the Kananaskis District and with current land use policies for fire protection. The water quality problems downstream of Calgary would best be solved by reducing municipal effluents and untreated storm sewer effluents, and reducing irrigation demands which reduce flows in the Bow River. Increasing flows from upstream sources will not eliminate these water quality problems, but will only mask them for a short while.

Thus, external demands for water quality improvement are best addressed in the long term by minimizing the problem at its source and not through yield or regime management of upstream areas.

The management objective of erosion and sedimentation limitation is inextricably tied to water quality management. In the Kananaskis District this concern is associated with planned developments including road and facility construction, but is also linked to the scouring effects of the present flow strategy. With regime improvement, the erratic flows responsible for scouring are eliminated or minimizedand therefore these objectives are complementary. With present orientations to land use preservation through fire protection soil disturbance is minimized. Some soil erosion and sedimentation of streams due to construction of recreational facilities is inevitable, and, as noted in Chapter 5.3.1 major land clearing activities in the Kananaskis District are already responsible for high concentrations of suspended sediment. Care in site selection and the use of mitigation measures available in the literature (Rothwell, 1971) can be useful in reducing this impact.

Flood limitation management in the Kananaskis District can have three basic thrusts. Forest fire protection will aid in reducing the peak runoff event, and this is compatible with regime management. The structures in place have some additional capacity after spring runoff, although they were not designed as flood preventative reservoirs and it is unlikely that they would be of much use in a high runoff year such as 1916. The implementation of a flood risk management plan would delimit those areas adjacent to the lakes and main river prone to flooding. Since the planned recreational and other forms of infrastructure will be subject to flooding under a yield oriented management strategy, these two objectives are potentially in conflict with each other. The minimi-

zation of excess flows under a regime strategy is consistent with the principles of flood protection.

Improvements to the stream and streamside environment can be developed in part by having more consistent seasonal flows and reducing the erratic flows which occur under the present management strategy. More consistent flows would provide a better aquatic environment for fish and other wildlife who depend on the riverine system for food, shelter and habitat. Such a strategy is in conflict with a peaking or yield oriented strategy which emphasizes high periodic flow or no flow releases over periods of time. Alternatively, regime management along the lines proposed in this study offers flow conditions which are responsive to the needs of aquatic users and therefore complements any attempt to improve the streamside environment.

As this assessment has shown there are several viable water management alternatives, although some are more suited than others to the present physical and structural environment in the Kananaskis District. Physically, the opportunities for yield improvement are not large because of the lack of mature timber for forest management schemes. Climatically, most of the precipitation is received in the District at higher elevations, often above treeline, and is more suited to non-vegetative management schemes. However the present land use orientations are such that neither snow or vegetation management techniques would be compatible or acceptable activities. Structural alternatives for improving water supply in the Kananaskis District have been reviewed by TransAlta Utilities and were found to be generally unavailable due mostly to political and economic reasons. Both the present water management strategy and that of yield improvement were found to be in conflict with internal instream flow requirements, external instream flow requirements below Calgary, and with irrigation requirements. However, they are compatible to some extent with the seasonal municipal demand, and

with downstream Apportionment and boundary flow requirements.

Physically, climatically and structurally the opportunity and potential for regime management is good. Regional yields are declining naturally due in part, to fire protection policies which encourage the development of a vibrant and mature forest cover, and to a lower yield climatic period. Structurally, the potential for regime improvement is good, although a conflict with the present management strategy will have to be reduced before any improvement in lake levels or streamflow can be realized. Regime management in the Kananaskis District was found to be compatible with: internal flow requirements for fish, aquatic habitat and water-based recreational activities; with external flow requirements above Calgary; municipal demand requirements; in special circumstances with instream flow requirements below Calgary; and with irrigation demands. The summer flows below Calgary, which would be supplemented to a minor extent by regime improvement, will still be below specified levels and water quality problems will continue to persist if present trends in municipal effluent discharge and irrigation withdrawls are maintained. Regime improvement could potentially be in conflict with Apportionment and boundary flow requirements since any redistributed flow in the summer period could be consumed by the irrigation districts leaving less volume for Apportionment and lower flows in the winter period.

Water quality management in the Kananaskis District is compatible with present land use policies which seek to preserve forest and soil thereby reducing suspended sediment loads in streams. Major land clearing projects associated with recreational developments will create some problems due to their proximity to the lakes and streams but these can be minimized. Water quality management is complementary to regime management since the more consistent

streamflows provide a healthier environment for aquatic users, and the dilution reduces the concentration of suspended sediment and other pollutants. The more consistent flow requirement for water quality improvement places it in conflict with the present management strategy and with yield management. External demands for water quality improvement, particularly in that stretch of the river below Calgary, should not affect Kananaskis operations since these problems are best handled with local solutions (ie. reduce effluent discharges to Bow River; reduce irrigation withdrawals thereby allowing more flow to satisfy instream requirements). The objective of erosion and sedimentation limitation is compatible with water quality management and regime management, since the latter minimizes the scouring effects of peaking flows and high spring runoff events. The present land use orientations towards environmental preservation and protection of forests also complements this object by minimizing hillslope and streamside erosion. Both the present strategy and yield management are in conflict with this objective since increases in runoff from forest removal and peaking flows contribute to sedimentation problems.

Flood control management in the Kananaskis District is compatible with regime improvement, water quality improvement and erosion and sedimentation limitation, as well as with present fire protection policies. The common objective between each is the reduction in peak runoff and streamflow events which, if unchecked, cause erosion and sedimentation of streams and a deterioration in water quality. The reservoirs provide some measure of flood control, however that is not their intended purpose. With continued fire protection of the forests, the disasterous fires of the 1920's and 1930's will not be repeated and the subsequent high runoff events associated with them will be eliminated. Flood management is in conflict with yield improvement, but is compatible with the present storage and peaking strategy as long as flows are below flood levels.

Management of the stream and streamside environment is complementary with regime management, water quality improvement, erosion and sedimentation limitation, and flood limitation management. Improving the aquatic environment by reducing peak flows and no-flow periods, and reducing scouring and exposure of stream bed and banks is best accomplished through regime improvement. Therefore,any management strategy which seeks to improve the aquatic environment will be in conflict with the present peaking management strategy and with yield management.

In Table 5.3b an attempt has been made to summarize, using a compatibility matrix, the relationship between various water management objectives and identified water demands. Three categories of compatibility are used to describe the conditions under alternate objectives: a) direct conflict, b) no positive or negative effects, or c) compatible. A change in the demand orientations by any of the use categories presented in the Table and discussed in the previous section above, may result in a change in compatibility.

There are numerous present and potential demand orientations and options which will influence the ultimate objectives of water management in the Kananaskis District. Internally, demands for peaking power and recreation are well established in fact as well as in policy form. The contradictory objectives of each demand will bring them into conflict and the resolution of this conflict could involve the use of political or economic tradeoffs. In addition, there are external demands for water, some of which are more real in terms of actual needs than others. The impact these external demands would have on water management in the Kananaskis District would depend on whether present rates of use continue or if conservation and cost measures reduce the demands. Most external water problems would best be solved by improving local useage conditions rather than turning to the headwaters areas for short-term solutions to what are potentially long-term problems.

Table 5.3b

Compatibility Matrix of Various Water Management Objectives in the Kananaskis District and Water-Based Demands

WATER MANAGEMENT OBJECTIVES	WATER-BASED DEMANDS							
	Hydro Peaking	Instream Flows Kananaskis R.	Instream Flows Bow R. Above Calgary	Municipal and Industrial Demands	Instream Flows Bow R. Below Calgary	Irrigation	Apportionment	Provincial Boundary Flows
Yield Improvement	B	A	C	C	C	C	C	C
Regime Improvement	A	C	C	C	C	C	B	A
Quality Improvement	A	C	C	C	C	C	B	B
Flood Limitation	A	C	C	B	C	B	B	C
Erosion and Sedimentation Limitation	A	C	C	C	C	C	B	B
Stream Environment Enhancement	A	C	B	B	B	B	B	B
Protection*	C	A	C	C	A	A	B	B

A - Conflicts with existing demand orientation
B - No positive or negative effects
C - Compatible with existing demand orientation
* Defined as the existing water management strategy in effect during 1975-80

Chapter 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 CONCLUSIONS

It is a fundamental truth that the water supply and demand patterns are unique for any river basin. Therefore the successful application of any water management objective to any region depends on a thorough understanding of these patterns and how they will vary in time and space. Potential water management objectives might include yield improvements, regime modification, quality improvement, erosion and sedimentation limitation, flood limitation, and stream and streamside environment improvement. In the Kananaskis District, water was first recognized as an important resource in 1947 when the Eastern Rockies Forest Conservation Board was created to administer the Forest Reserves for watershed improvement. The management objective at that time was described as being one of obtaining the greatest possible flow in the Saskatchewan River and its tributaries. It was only after this that research into the hydrology of the region was initiated, so clearly the original objective was not implemented based on a sound understanding of water supply and demand configurations.

In 1973 the Province of Alberta undertook a series of public hearings into land use and resource development in the eastern slopes, prior to developing a land use policy for the region. In studies done to provide background information for these hearings, and particularly in the Foothills Resource Allocation Study, areas were evaluated on their ability to supply water, hence the focus again on water yield. In all of the Forest Reserve only 5 percent of the area was rated good or excellent for water production. Since no water demand studies had been undertaken, and no water management objectives had been established, the yield orientation in these studies was arbitrary and indicated

assessment bias. Ultimately, the public overwhelmingly endorsed protection of wildlife and natural resources and the development of outdoor recreation as desirable objectives. In 1977 the government finalized the Policy for Resource Management of the Eastern Slopes and in it declared the main objective to be the maintenance of normal streamflow and quality through watershed protection. As before, this objective was not developed based on an assessment of water supply and demand patterns. It is unrealistic to assume that one water management objective could suit the requirements of the entire Eastern Slopes since the use patterns are unique in each basin or region. Therefore, in this study, the author undertook a regional analysis designed to establish the actual and potential water supply - water demand patterns for the Kananaskis District as a means of determining which management objectives are viable and which alternatives may be exploited.

The natural water supply characteristics were predicted using innovative mapping and assessment techniques that have proven useful elsewhere. Knowledge of generalized soil/water relationships, supported with precipitation data and estimates of evapotranspiration was used to obtain a representative picture of natural water supply variations within the region. The highest runoff of over 1150 mm (46 in.) is generated from places along the Continental Divide and the upper ridges of the Kananaskis Range because of higher amounts of precipitation and less evaporation due to colder temperatures and less retention storage. At intermediate and lower elevations, lower amounts of precipitation and higher rates of evapotranspiration combine to reduce runoff to less than 40 percent or 250 mm (10 in.) of precipitation received. The total annual mean runoff has changed in response to a lower yield climatic period in combination with man's storage and diversion developments and forest regeneration. Natural runoff preceding development in 1933 approximated 547,670 dam^3 (444,000 Ac.-ft.), while the contemporary runoff has declined to 447,760 dam^3 (363,000 Ac.ft.).

The seasonal distribution of the water supply has been significantly altered through changes in storage and operational strategy. Discharges in the post-development period of 1933-62 were 10.9 cms (385 cfs) or three times greater, during the January through March period, than prior to development. In addition the monthly mean flows in the summer period were reduced below the natural extreme minimum flows of the pre-development period. Contemporary (1975-79) flow patterns for the month of June at 15.1 cms (533 cfs) are one-quarter as large as the natural flow prior to development and one-half the size of the post-development flow. In contrast the present mean winter flows of 13.6 cms (482 cfs) are approximately four times as large as the natural flow. Contemporary daily flows are highly variable since they reflect the use of water releases to produce peaking power. Flow releases have varied over 14.2 cms (500 cfs) within a 24 hour period and have actually been as low as 0.056 cms (2.0 cfs).

Storage level variations during the last two decades reflect an increasingly greater influence of changing operational strategies. In the early years of operation, the three major lakes were filled quickly during spring runoff, remained high in the summer and were drawn down over the fall-winter period. Currently, drawdown and filling rates are such that water levels in the two upstream lakes are as much as 3 m (9.8 ft.) to 6 m (20 ft.) below full supply level in July.

Demands on water originating in the Kananaskis District are derived from both internal and external sources. TransAlta Utilities has developed 209,700 dam^3 (170,000 Ac.-ft.) of storage in the Kananaskis Lakes and Barrier Reservoir to hold runoff for later use in peaking power production. Although the local generating capacity represents 10 percent of Bow River hydro capacity and 1 percent of total TransAlta Generating capacity, the Kananaskis plants comprise a large portion of peaking generation and reserve capacity. Coupled with a 7.7 percent increase in energy demand per year to 1988 will be a decrease in reserve capacity to 17 percent of the total 6650 MW. Since hydro

operations are flexible they are called on to help with the daily and seasonal peak demands and provide a necessary portion of the energy reserve. With increases in peak energy demands and a decrease in energy reserve in this decade, it is probable that present hydro operations will continue and that the regime patterns depicted in Chapter 2.2 will remain characteristic of daily and seasonal flow conditions.

Recreational demands on the water resources of the Kananaskis District from Kananaskis Provincial Park and Kananaskis Country will comprise consumptive and non-consumptive uses. Consumptive uses will be small and will largely be replaced by increases in local yields from cover changes. Non-consumptive uses such as fishing, boating and aesthetic viewing will focus on the main river and lakes where several recreational facilities including alpine villages and campgrounds are to be built. However, lake levels are often well below optimum levels and streamflows are extremely variable during the peak summer period suggesting that these activities may be hampered.

Instream flow requirements in the Kananaskis River for fish, aquatic habitat, and water-based recreational uses including quality and aesthetics have been evaluated using the Tennant instream flow methodology. During the summer period actual flows above Barrier Lake are often below the levels required for good conditions and have in the most recent 1978-80 period violated even the minimum required flows to sustain fish. Generally, water quality exceeds minimum requirements except during high flow periods in the summer when suspended sediment concentrations increase to above acceptable levels.

Externally, instream flow requirements in the Bow River above Calgary were historically below the 39.6 cms (1400 cfs) level during the winter months, but additional flow releases from the Bow River reservoirs in recent years have supplemented these flows so that they now satisfy the requirements.

Municipal and industrial demands appear significant on the surface but in fact the short-term withdrawals are more than counter-balanced by return flows from the sanitary and storm sewer systems. The problem which the City of Calgary has with supplying water to customers is the result of over-use spawned by flat-rate charges which apply to over 80 percent of the residential homes, and has nothing to do with availability of supply since the City only took 2 percent of the flow from the Bow River in 1980. Although the water returned to the Bow River is impaired in quality, the quantity is of use in meeting downstream commitments to Apportionment.

Instream flow requirements (of 39.6 cms (1400 cfs) below Calgary at Bassano have been violated during the drier than normal flow years of 1977 and 1979 and even in a near-normal flow year like 1980 during the summer period. Large irrigation withdrawals are responsible for the low flows, and in combination with the presence of organic and inorganic pollutants from municipal sources, the water quality in this stretch of the river often fails to meet even minimum provincial standards.

Irrigation demands represent the largest quantitative water withdrawal from the Bow River. Actual consumptive use by the three irrigation districts amounted to over 30 percent of the 2,580,000 dam^3 (209,160 Ac.-ft.) flow in the Bow River as measured at Calgary in 1980. The growth in irrigable hectares is forecast at a nominal rate of about 4 percent per year. Given the present unit rate of consumptive use, in a dry year flow similar to 1977, flows in the Bow River as measured at Calgary would be depleted to 50 percent of the total as early as 1986. By 1996, at present rates of growth and consumptive use, the irrigation districts will be consuming approximately 50 percent of the average annual flow in the Bow River as measured at Calgary. Of course changes in consumptive use through improvements in efficiency, increases in internal storage, or increases in water costs may lead to reductions in total diversion and consumption.

The Apportionment Agreement provides for one-half the flow or 2.6 million dam^3 (2.1 million Ac.-ft.) of the South Saskatchewan River to be passed downstream on a calendar basis. In a normal flow year this requirement is easily satisfied, however in a dry year such as 1977, the total flow passed downstream of 3,350,000 dam^3 (271,600 Ac.-ft.) represented 40 percent of the normal average and only exceeded the minimum requirement by 750,000 dam^3 (608,000 Ac.-ft.). With continued increases in total consumptive uses in all three contributing basins and no change in unit consumptive usage patterns, this margin of excess could be utilized probably before the end of this century with a repeat of a dry flow year. An additional flow constraint of 42.5 cms (1500 cfs) at the provincial boundary with Saskatchewan is an attempt to ensure a reasonable distribution of flow throughout the year. Streamflow records indicate that this limit has been violated several times in the past 15 years, most noticeably during fall-winter and spring periods prior to runoff.

Having identified the water supply patterns and the internal and external water demands, one can now assess how different water management objectives will influence the disposition of flows and which objectives solve or exacerbate present and potential conflicts. Under the current policy of protection and maintenance of existing streamflow and lake level conditions TransAlta Utilities would continue with the storage and peaking strategy outlined in Chapter 4.3.3 and 4.4.3. This strategy is in direct conflict with internal instream flow requirements particularly for fisheries use and for aquatic habitat, but also for water-based recreational activities such as boating and sport-fishing. The strategy complements external instream flow requirements and, to some extent, municipal demands for seasonally available water. The strategy of storage accumulation during the summer is in conflict with the peak summer demands of the irrigation districts. It is these same irrigation demands which are responsible for the violations of instream flows below Calgary, not the upstream flow strategy. The Apportionment and flow requirements at the provincial boundary are complemented by the

existing strategy since it provides for a better distribution of flow in the traditional low flow winter period.

The potential for yield management in the Kananaskis District is not large. It was estimated that a maximum 5 percent increase or 24,660 dam^3 (20,000 Ac.ft.) in flow might be derived from selective forest management or snow management techniques; however, there is some question as to the viability of these methods given existing land use policies. This small additonal flow would have little impact on current TransAlta operations, and therefore no change in storage and flow strategy would be required. Thus, internal instream flow requirements for fish, aquatic habitat and waterbased recreation would be in conflict with this objective. External demand requirements would be little affected by this minor supplementation to flow, although those uses which were complemented under the existing objective of protection would continue to be satisfied under yield management.

Regime management is compatible with existing land use policies in the Kananaskis District which stress fire prevention, since the maturing of a forest ultimately leads to delayed snowmelt, better percolation to storage, reduced runoff and less erosion and sedimentation of streams. Major changes in regime have occurred through structural control and it is these same structures which can produce the most effective change in regime. Providing instantaneous discharges from the Pocaterra hydro plant of 6.5 cms (230 cfs) during the April to September period would satisfy the instream flow requirements for fisheries, aquatic habitat and water-based recreation, in addition to reducing scouring by eliminating the highly erratic peaking flows. Although lower instantaneous flows might be unavoidable in low flow years, the flow releases should never be allowed to fall below 1.5 cms (53 cfs) which is the minimum flow necessary just to sustain the above activities. With regular, instantaneous flows, regime improvement is in conflict with the current TransAlta practice of peaking, but

not with hydro power generated by run of river flows. A more even distribution of flows would complement external instream flow requirements and municipal demand requirements. Some additional flows [approximate 30,000 dam^3 (24,320 Ac.-ft.)] would be available during the summer period and this would complement flow requirements below Calgary and irrigation demands. Actual benefits may be less than apparent since the irrigation districts could easily absorb the extra water by 1982 at present rates of growth, leaving little for supplementing instream flows. Apportionment is not negatively affected unless the re-distributed flows are consumed by the irrigation districts whereas the border flow requirement will suffer further violations in the fall-winter and spring period due to reduced flows.

Other water management objectives including flood limitation, water quality improvement, erosion and sedimentation limitation, and stream and streamside habitat improvements are all complementary with various aspects of regime improvement. Flood limitation is compatible with regime improvement by encouraging forest protection and more measured flow releases which combine to minimize flood damage to low-lying valley areas. Water quality improvement is compatible with regime improvement since suspended sediment due to scouring from the peaking flows and from forest removal is minimized. Similarly, the stream environment is improved with regime management due to more consistent coverage of the stream bed and assured supplies for fish and wildlife habitat and human uses.

It is apparent from this analysis that, regardless of the management objective in the Kananaskis District there will be conflicts between TransAlta Utilities and the water-based recreational goals of the province of Alberta. Under the present system of operations, it is suspected that the fisheries and recreational resources are being hampered and this conflicts with provincial ambitions for sport fishing and boating on the lakes and main river systems. Under a system of regime

improvement, in which uniform instantaneous flows are linked to upstream water levels, instream flow requirements for fish, aquatic habitat and water-based recreational needs are satisfied. The storage and peaking strategy of TransAlta is not satisfied under this management objective, however power can still be produced under this system by run of river operations and no loss of revenue need occur. The loss of peaking potential in the Kananaskis District can be made up for by other sources and several tradeoffs, including allowing for larger releases from other plants, assisting with the development of new hydro projects or allowing for larger flows in exceptional power demand circumstances, are available for consideration.

Externally, water supplies in the Bow River are being strained, particularly in dry years because of large water demands from the irrigation districts downstream. While any additional flow available under regime or yield improvement measures could be interpreted as being seasonally compatible with irrigation requirements, the actual amounts made available from the Kananaskis District would be small and would do nothing to solve the longer term problem of potential demand exceeding available supply. In fact the major problems in the Bow River downstream of Calgary will not be resolved by short-term gains from upstream management. Reductions in sanitary and storm sewer effluent discharges and improvements in irrigation efficiency will go a long way towards ameliorating water quality, quantity and regime problems in the lower Bow River.

6.2 RECOMMENDATIONS

The analysis of physical information and the derivation of major climatologic and hydrologic patterns preceded a discussion of regionally appropriate management alternatives. There are several areas where more specific physical information would aid in a more critical analysis of the viability of various water management objectives. The following is a brief outline of recommended improvements in field data

sources, demand studies and management procedures.

It was apparent during the climatic analysis, that significant gaps in data exist, particularly for the high elevation alpine and sub-alpine areas. More information on precipitation and wind flow patterns is necessary before an accurate analysis of runoff characteristics is possible. The installation, maintenance and monitoring of instrumentation for these and other meteorologic parameters would prove invaluable for TransAlta Utilities Ltd., and Alberta Environment purposes in flow forecasting, and would fit well with Alberta Recreation and Parks' desire for better interpretive physical information. The information derived would also assist in a definition of alpine hydrometeorology and analysis of the potential techniques for modifying precipitation/runoff relationships. Of particular importance are those areas, identified in Chapter 3, with the highest precipitation, the upper slopes of the Continental Divide, Kananaskis, and Spray Mountains.

The hydrology of the District is monitored only to the extent that it meets TransAlta Utilities requirements. The installation of a flow gauge at the outlet of Smith-Dorien Creek would help illustrate the effects of inter-basin transfer on total water yield, as well as on the intra-seasonal variations of flow and could be used to improve on the water balance and runoff scenario described in Chapter 4. A similar installation of a gauge on Pocaterra Creek would improve information on the hydrology and water yield characteristics of the Highwood Pass area. Flow releases out of Lower Kananaskis Lake provide the only information on water supplies in the Kananaskis River between the upper basin and Barrier Reservoir. The placement of a flow gauge upstream of Barrier Reservoir in the vicinity of Marmot Creek could be used to determine the water yield which that area outside of the upper basin contributes. It would also clearly delineate the frequency and amount of flow variations in the Kananaskis River as a result of peaking operations, and would be useful in subsequently defining desirable flow level criteria for future management interests.

The necessity for current and immediate demand studies which respond to stated policy objectives is a prerequisite to solving potential use confrontations. In the past, the demand for peaking power production dominated water management within the Kananaskis District, while irrigation withdrawals and contributions to flow regulation were dominant demands downstream. Present and future demand orientations will change both internally and externally. Internally the shift in dominant use from power production to recreational/environmental uses is apparent from recent moves by the provincial government (ie. Kananaskis Provincial Park and Kananaskis Country) in line with its land use and resource policy. A potential conflict in water management within the Kananaskis District is inevitable given the daily and seasonal imbalances in current operations. The discussion has shown that the potential for even larger withdrawals downstream from irrigation, and larger effluent discharges from municipal sources will place more stress on the Bow River in the coming decade. Although upstream areas could be managed for regime or yield improvement to provide some minor flow assistance, major improvements to Bow River flows could be achieved through improvements in irrigation efficiency, and through reductions in effluent discharges from municipal sources.

Several recommendations can be made which specifically address the problems and conflicts in water management, both with the Kananaskis District and downstream in the Bow River basin.

Operating licenses issued under the authority of the Minister of Environment, should be granted only after the potential effects of changing hydrologic conditions on the riverine system are documented for a particular operational strategy. In addition, the licenses should contain guidelines for regulating the size of flow releases and fluctuations in water levels. This would ensure that each time a change in operational strategy is desired, new license applications would be required to be submitted, which describe how the change in strategy would influence the river environment.

There should be specific recommendations in the Policy for Recreation Development of Kananaskis Country which designate the daily and seasonal water levels and streamflows compatible with recreational needs. The application of these guidelines to the Kananaskis District would provide a physical constraint within which competing uses for water would have to comply.

A considerable amount of land clearing is, and will be, taking place in conjunction with planned recreational developments. A water quality monitoring station should be installed near the mouth of the Kananaskis River to measure the effects of this activity, and also the inputs of sewage from the Alpine villages, campsites and golf course.

Without proper water demand studies, it is difficult for the provincial government to know how to determine future needs and policies. The implementation of a regional analysis for each drainage basin would help to delimit the water supply/demand variations and the prospective conflicts in use.

Having completed an analysis of the water supply and demand variations, the provincial government should then establish a priority system of water use to be followed during years of less than average flow. The priority system would have to be reviewed periodically to maintain flexibility towards changing demand orientations.

In support of its policy to utilize available water supplies to the fullest in each basin before considering interbasin transfers, the provincial government should seek ways to encourage more efficient use of water. In the irrigation districts this could be accomplished several ways, including modernizing the delivery and application systems; priorizing water deliveries to high value crops during periods of low flow conditions; and raising the cost of water.

Similarly, the City of Calgary should consider the use of water meters in an effort to reduce water consumption. The use of water meters and user rates would reduce demands and delay the need for plant expansions and subsequent increases in expenditures.

The quality of the Bow River below Calgary is directly affected by the storm and sanitary sewer runoff from the city. As the city increases in size, greater volumes of untreated storm effluent drain into the river, rendering the water undesirable for human use. Treating the storm water runoff would help alleviate some of the water quality concerns below Calgary during low flow periods.

The rationale for conducting a regional analysis to determine regional water management problems and prospects was espoused four decades ago. In several instances it has proven to be an effective methodology in helping to develop State, district, and basin water management programs in the United States. Failure of traditional analysis methods to adequately incorporate watershed concerns into the planning process is clearly evident from recent resource studies and subsequent policies governing resource use in Alberta. Historical attitudes presuming the function of a watershed as being a supplier of a high yield of water, are a major stumbling block to the acceptance of other water management objectives which may be more regionally appropriate.

The methodology used in this study assumes that only after a thorough analysis of water supply/demand patterns, can truly viable management alternatives other than yield improvement be evaluated. A lack of detailed physical information on hydrological and meteorological parameters is often the reason for an incomplete understanding of water supply characteristics in mountainous regions. Several innovative, yet valid, techniques have been used to help fill data gaps and produce a better understanding of these characteristics. Since few demand studies had been conducted and those that involved

water were left incomplete, the demand analysis in this report is an attempt to synthesize the main factors which will influence supply variations. Ultimately, the various water based demand conflicts will become more visible as supplies tighten, especially in a dry year, although several viable alternatives exist to reduce the degree of conflict between uses.

The regional analysis conducted for this study uses available information on water supply and demand patterns, to assist in the assessment of water management alternatives. The methodology is simple and flexible since it can accommodate potential changes in management structure as they change with future supply/demand orientations in the Kananaskis District. Although the hydrometeorological characteristics of the District are unique, the methods outlined in this study for relating the physical base to management alternatives are transferable in their application to studies elsewhere.

BIBLIOGRAPHY

Acres Consultants Ltd. 1980 City of Calgary Water Conservation Study report to City of Calgary Engineering Department, Waterworks Division, Calgary, 23 pp.

Alberta, Energy and Natural Resources 1977 A Policy for Resource Management of the Eastern Slopes, Eastern Slopes Publication, Resource Information Services, Energy and Natural Resources, Edmonton 19 pp.

Alberta, Energy and Natural Resources 1980 Kananaskis Country Integrated Management Plan: Terms of Reference, Resource Planning Branch, Resource Evaluation and Planning Division, Edmonton, 23 pp.

Alberta, Energy and Natural Resources, 1982, personal communications, Mr. Lanny Coulson, Integrated Management Planning Section, Resource Planning Branch, Edmonton

Alberta, Energy Resources Conservation Board, 1980 Alberta Electric Industry, Annual Statistics 1980, ISSN-0706-1420, Vol. 10, E.R.C.B. publ., Calgary, 34 pp.

Alberta, Energy Resources Conservation Board, 1981 Alberta Electric Industry, Monthly Statistics, January-December, E.R.C.B. publ., Calgary, 7 pp. each

Alberta Environment 1981a South Saskatchewan River Basin Planning Program: Phase II Water Quality, Water Quality Control Branch, Pollution Control Division, Calgary, 58 pp.

Alberta Environment 1981b, South Saskatchewan River Basin Eutrophication Control Study, 1980/81 Interim Report, Water Quality Control Branch, Pollution Division, Calgary, 26 pp.

Alberta Environment 1982, personal communication, Mr. Jack Glenn, Planning Division, Water Management Section, Calgary

Alberta, Environment Conservation Authority 1974 Land Use and Resource Development in the Eastern Slopes, Interim Report No. 3, Bow River Basin, submitted to Alberta Environment, Edmonton, 69 pp.

Alberta, Recreation and Parks 1977, Policy for Recreation Development of Kananaskis Country, Government of Alberta Publication, Edmonton, 36 pp. (includes Revisions, 1979)

Alberta Recreation and Parks 1978 Kananaskis: Alberta's First Mountain Provincial Park, Information Bulletin Parks Division, Edmonton, 4 pp.

Alberta, Recreation and Parks 1980, Kananaskis Country, Information Pamphlet

Alberta Recreation and Parks, 1982, personal communications, Mr. Peter Taylor, Recreation Development Division, Recreation and Parks, Calgary

Anderson, H.W. 1963 Managing California's Snow Zone Lands for Water, U.S. Dept. of Agric., For. Serv., Pac-Southwest For. and Range Expt. Station, Res. Pap. PSW-6, 28 pp.

Anderson, H.W. 1967 Snow Accumulation as Related to Meteorological, Topographic and Forest Variables in Central Sierra Nevada California, Int. Assoc. Sci. Hydrol. Publ. No. 78, p. 215-224

Anderson, H.W., R.M., Rice and A.J. West 1958 Snow in Forest Openings and Forest Stands, Proc. Soc. Amer. Forestry, p. 46-50.

Barnetson, R.B. 1980 1979 Return Flow for Irrigation Districts in Alberta, Inland Waters Directorate Water Survey of Canada, Environment Canada, Calgary.

Barnetson, R.B., 1981 1980 Return Flow for Irrigation Districts in Alberta, Inland Waters Directorate, Water Survey of Canada, Environment Canada, Calgary

Barry, R. and R.J. Chorley 1969 Water, Earth and Man, Metheun and Co. Ltd., London, 588 pp.

Bayha, K., 1978 Instream Flow Methodologies for Regional and National Assessments, Instream Flow Information Paper No. 7, U.S. Fish and Wildlife Service, Fort Collins, Colorado, 97 pp.

Bayrock, L.A. and T.H.F. Reimchen 1977 Surficial Geology and Erosion Potential: Rocky Mountains and Foothills of Alberta, open file report, Alberta Research Council, Edmonton.

Bergen, J.D. and R.H. Swanson 1964 Evaporation from a Winter Snow Cover in the Rocky Mountain Forest Zone, Proceedings 32nd Western Snow Conference, p. 52-59.

Bethlahmy, N. 1972 Comments on "Effects of Forest Clear-Felling on the Storm Hydrograph", in Water Resources Research, 8 (1): p. 166-170.

Bielenstein, H.U. 1969 The Rundle Thrust Sheet, Banff Alberta: A Structural Analysis, unpub thesis (Ph.D.) Queens University, Kingston, 148 pp.

Bruce, J.P. and R.H. Clark 1966 Introduction to Hydro-meteorology, Pergamon Press, Toronto.

Byrne, A.R. 1968 Man and Landscape Change in the Banff National Park Area before 1911, in Studies in Land Use History and Landscape Change, National Park Series No. 1, University of Calgary, Calgary.

Calgary Power Ltd. 1973 Storage of Water in the Bow River Basin, brief submitted to Environment Conservation Authority hearings into Land Use and Resource Development in the Eastern Slopes, Calgary, 27 pp.

Calgary Power Ltd. 1978 personal communications, Ted Shulte, concerning changes to the Kananaskis drainage network and operational strategies, Calgary.

Calgary Power Ltd. 1979 personal communication, Ted Schulte, Liason Officer, Calgary Power Ltd., Calgary.

Calgary Power Ltd. 1980 personal communication, Pat Doyle, Liason Officer, Water Management Division, Calgary.

Calgary Regional Planning Commission 1973 Land Use and Resource Development in the Eastern Slopes: Bow River Watershed Basin, Info. Bulletin No. 6, Environment Conservation Authority, Edmonton, 44 pp.

Canada, Energy Mines and Resources 1973 National Atlas of Canada, Mapping Division, Dept. of Energy Mines and Resources, Ottawa, 83 plates.

Canada, Statutes 1911 An Act Respecting Forest Reserves and Parks, 1-2 George V, Chapter 10.

Chow, V.T. 1964 Handbook of Applied Hydrology, (ed), McGraw-Hill Pub., New York.

City of Calgary 1982(a), personal communications, Mr. Derek Harrison, Engineer, City of Calgary Waterworks Division

City of Calgary 1982(b), personal communication, Mr. Hugh Quintila, Manager-Sewer Division, City of Calgary Waterworks Division.

Crockford, M.B.B. 1949 Geology of the Ribbon Creek Area, Alberta, Research Council of Alberta, report No. 52.

Curry, G.E. and A.S. Mann 1965 Estimating Precipitation on a Remote Headwater Area of Western Alberta, Proc. 33rd Annual Meeting, Western Snow Conference, p. 53-66.

Dybvig, W. 1976 Schedule of Gross Diversions for Irrigation from Bow River, Appendix 1, Planning Division, Alberta Environment, Calgary, 11 pp.

Dybvig, W. 1979 Input to Kananaskis Country - I.M.P. Process, Planning Division, Alberta Environment, Calgary, 15 pp.

Duffy, P.J.B. and R.E. England 1967 A Forest Land Classification for the Kananaskis Research Forest, Alberta, Canada, Forestry Branch, Forest Res. Lab.. Calgary, Internal Report A-9, 20 pp.

Eastern Rockies Forest Conservation Board 1964 'Recreation: General Policy Statement', Calgary, 2 pp.

Electric Utility Planning Council, 1981 Power Generation in Alberta: 1981-2005. System Evaluation and Reliability Committee, EUPC, Edmonton, 48 pp.

Environment Canada 1977a Historical Streamflow Summary to 1976 - Alberta, Inland Waters Directorate, Water Resource Branch, Water Survey of Canada, Ottawa

Environment Canada 1977b Snow Data and Forecast Summary, Inland Waters Directorate, Water Survey of Canada, Calgary District 50 pp.

Environment Canada 1978 Historical Water Levels Summary to 1976 - Alberta, Inland Waters Directorate, Water Resources Branch, Water Survey of Canada, Ottawa.

Environment Canada 1980 Historical Streamflow Summary to 1979 - Alberta, Inland Waters Directorate, Water Resources Branch, Water Survey of Canada, Ottawa.

Environment Canada 1981 Historical Streamflow Summary to 1980 - Alberta, Inland Waters Directorate, Water Resources Branch, Water Survey of Canada, Ottawa.

Ferguson, H.L. and D. Storr 1969 'Some current Studies of Local Precipitation Variability Over Western Canada' in Proceedings Supp. on Water Balance in North America Banff, Alberta, Am. Water Resources Assoc. Proc. Series No. 7, p. 80 - 100.

Ferguson, H.L. et al. 1971 Theoretical Clear-Sky Effective Insolation Over a Small Mountain Basin, Environment Canada, Atmospheric Environment Service, Climatological Studies, No. 21, Toronto, 45 pp.

Fisera, Z. 1977 'Snow Accumulation and Melt Patterns in Tree Line Stands of Marmot Creek Basin', in Swanson and Logan (ed.), Proc Symp. Alberta Watershed Research Program, Info. Rep. NOR-X-176 Canadian Forest Service, Edmonton, p. 96-109

Golding, D.L. 1970a 'Computer Mapping of the Marmot Creek Snowpack and the Influence of Topographic and Vegetative Variables on the Pack', in Proc. Third Forest Micro-climate Symp., Canadian Forestry Service, Calgary, p. 76-83.

Golding, D.L. 1970b 'Research Results from Marmot Creek Experimental Watershed, Alberta Canada', in Proc. Symp. Results of Research on Representative and Experimental Basins, Wellington, New Zealand, I.A.S.H. Publication, No. 96, p. 397-404.

Golding, D.L. 1974a 'Managing Lands for Water', in Proceedings: Research Management Seminar, Edmonton, Alberta, Canadian Forestry Service, Northern Forest Research Centre, Info. Rep. NOR-X-13, 79 pp.

Golding, D.L. 1974b The Correlation of Snowpack with Topography and Snowmelt Runoff on Marmot Creek Basin, Alberta, Atmosphere, Vol. 12 No. 1 p. 31-38

Golding, D.L. 1977a 'Watershed Treatment to Alter Snow Accumulation and Melt Rates', in Proc. Symp. Alberta Watershed Research Program, Swanson and Logan (ed.), North. For. Res. Cen., Info. Rep. NOR-X-176, Edmonton, p. 237-255.

Golding, D.L. 1977b 'Snowpack Evaporation During Chinooks Along the East Slopes of the Rocky Mountains', in Proc. Symp, Hydrometeorology, Toronto.

Golding, D.L. 1978 'Calculated Snowpack Evaporation During Chinooks Along the Eastern Slopes of the Rocky Mountains in Alberta', in Jour. Applied Meteorology, Vol. 17, No. 11, p. 1647-1651.

Goodell, B.C. 1958 A Preliminary Report on the First Year's Affects of Timber Harvesting on Water Yield from a Colorado Watershed, U.S. Dept. Agric., For. Serv., Rocky Mountain For. and Range Exp. Stat., Paper No. 36.

Goodell, B.C. 1967 'Watershed Treatment Effects on Evapotranspiration', in Proc. Int-Symp. Forest Hydrology, Pergamon Press, N.Y., 813 pp.

Gray, D.M. 1970 Handbook on the Principles of Hydrology, Secretariat, Canadian National Committee for the International Hydrological Decade, National Research Council of Canada, Ottawa.

Gysi, M. 1981 Measuring the Needs for Interbasin Transfers Canadian Water Resources Journal, Vol. 6, No. 2, p. 43-53.

Gysi, M. and G. Lamb 1977 An Example of Excess Urban Water Consumption, Canadian Journal of Civil Engineering, 4(1), p. 66-71.

Halliday, J. and D. Mathewson 1971 A Guide to the Geology of the Eastern Cordillera Along the Trans-Canada Highway Between Calgary Alberta and Revelstoke, British Columbia, Alta. Soc. Petr. Geol.

Hanson, W.R. 1973 The Eastern Rockies Forest Conservation Board: A History, Eastern Rockies Forest Conservation Board Publication, Alberta Energy and Natural Resources, Edmonton.

Hendry, M.C. 1914 Report on Bow River Power and Storage Investigations, Water Power Branch, Department of the Interior, Ottawa, p. 115-118.

Hewlett, J.D. and A.R. Hibbert 1961 'Increases in Water Yield after Several Different Types of Forest Cutting', in Int. Assoc. of Sci. Hydrology, Vol. 6 p. 5-17.

Hewlett, J.D. and J.D. Helvey 1970 'Effects of Forest Clear-Felling on the Storm Hydrograph', in Water Resources Research, Vol. 6 p. 768-782.

Hibbert, A.R. 1967 'Forest Treatment Effects on Water Yield', in International Symposium on Forest Hydrology, Penn. State Univ., Pergamon Press Inc. N.Y. p. 527-543.

Hoover, M.D. 1969 'Water Yield Improvement for the Timber Snow Zone of the Central Rocky Mountains Area', in Workshop on Snow and Ice Hydrology, Proc. Colorado State Univ., p. 111-116.

Hillman, G. 1979 personal communications, Scientific Officer, Forest Hydrology Section, Northern Forest Research Centre, Edmonton.

Idaho Water Resources Board 1968 Idaho Water Resources Inventory, Dept. of Water Administration, Boise, Idaho, includes Atlas and Appendix Supplement, 598 pp.

Idaho Water Resources Board 1972 Interim State Water Plan: Interim Report, Dept. of Water Administration, Boise, Idaho, 265 pp.

Idaho Water Resources Board 1974 The Objectives: State Water Plan - Part One, Dept. of Water Administration, Boise, Idaho, 42 pp.

Idaho Water Resources Board 1976 The State Water Plan - Part Two, Dept. of Water Resources, Boise, Idaho, 162 pp.

Jackson, L.E. 1977 Quaternary Stratigraphy and Terrain Inventory of the Alberta Portion of the Kananaskis Lakes, unpub. thesis (Ph.D.) University of Calgary, Calgary.

Janz, B. 1977 'Estimation of Average Annual Precipitation in the Mountain Parks', in Proc. Alberta Watershed Research Program Symposium, Swanson, R.H. (ed.), p. 178-186.

Janz, B. and D. Storr 1977 The Climate of the Contiguous Mountain Parks: Banff-Jasper-Yoho-Kootenay, Environment Canada, Atmospheric Service, Project Report No. 30, Toronto, 324 pp. (unpub. manuscript).

Jaques, D.R. and A.H. Legge 1974 'Living Environment: Vegetation' in The Mountain Environment and Urban Society - Kananaskis Pilot Study, Kananaskis Centre for Environmental Sciences Publication, University of Calgary, Calgary, p. 193-279.

Jeffrey, W.W. 1964 'Watershed Research in the Saskatchewan River Headwaters', in Hydrology Symposium No. 4, Research Watersheds, Guelph, Ontario, p. 79-139.

Jeffrey, W.W. 1965a 'Experimental Watersheds in the Rocky Mountains, Alberta, Canada Symposium Int. Assoc. of Sci. Hydrology, Budapest, Publication No. 66, p. 502-521.

Jeffrey, W.W. 1965b 'Wildland Watershed Management and Wildlife and Fishery Biology: Some Common Interests and Potential Conflicts', in Canadian Soc. Wildlife and Fish Biology, Occas. Paper No. 1, p. 12-21.

Jeffrey, W.W. 1965c 'Vegetation, Water and Climate: Needs and Problems in Wildland Hydrology and Watershed Research', in Proc. Symp. on Water and Climate, Report No. 2, Water Studies Institute, Saskatoon, Saskatchewan.

Jeffrey, W.W. 1967 'Wildland Watershed Management Research in Canada', in Forest Hydrology, W.E. Sopper and H.W. Lull (ed.), Permagon Press, Oxford, p. 21-30.

Johnston, G.C. 1980 Input Requirements for the South Saskatchewan River Basin Planning Program, correspondence from City of Calgary, Engineering Department (Waterworks Division) to Planning Services Branch, Alberta Environment, 8 pp.

Karkanis, P.G. 1972 Soils of the Kananaskis Valley, Environmental Sciences Centre (Kananaskis), unpub. research report, No. 1, 53 pp.

Kellerhals, R. and C.R. Neill and D.J. Bray 1972 'Hydraulic and Geomorphic Characteristics of Rivers in Alberta', in River Engineering and Surface Hydrology Report 72-1, Alberta Research Council.

Kirby, C.L. 1973 The Kananaskis Forest Experiment Station, (History, Physical Features and Forest Inventory), Northern Forest Research Centre, Info. Rep., NOR-X-51, Edmonton, 50 pp.

Laycock, A.H. 1952-55 Reports to the Eastern Rockies Forest Conservation Board: Soil Surveys - Three Seasons, unpub. internal report, Calgary.

Laycock, A.H. 1954 Precipitation in the Forest Reserve: Its Distribution and Relation to Watershed Planning, Eastern Rockies Forest Conservation Board (internal report) , Calgary 14 pp.

Laycock, A.H. 1957a A Physiographic Classification of Soils for Land Use Planning on the Eastern Slopes of the Canadian Rockies, unpub. thesis (Ph.D.), University of Minnesota, 453 pp.

Laycock, A.H. 1957b Precipitation and Streamflow in the Mountain and Foothill Regions of the Saskatchewan River Basin, Prairie Provinces Water Board Report No. 6, Regina, 48 pp.

Laycock, A.H. 1958 Soil Surveying in Mountain Watersheds: The Problem and One Solution, Annual Meeting, Assoc. Amer. Geographers, Santa Monica, California, 6 pp.

Laycock, A.H. 1961 Hydro-Meteorology in Watershed Management Planning on the Eastern Slopes of the Canadian Rockies, unpub. paper, C.A.G. Annual Meeting, Montreal.

Laycock, A.H. 1966 'The Need for a Regional Approach in Watershed Management Planning', in Proc. First Annual Meeting of the American Water Resources Association, held at Univ. of Chicago, Dec. 1965, Urbana, Illinois, p. 146-154.

Laycock, A.H. 1967 Water Deficiency and Surplus Patterns in the Prairie Provinces, Water Board Report No. 13, Regina, 185 pp.

Laycock, A.H. 1973 Land and Water Resource Development in the Eastern Slopes, brief presented to Environment Conservation Authority hearings into Land Use and Resource Development in the Eastern Slopes, Edmonton 35 pp.

Laycock, A.H. 1978 'Precipitation Mapping in Alberta', in Essays on Meteorology and Climatology, Univ. of Alberta, Studies in Geography, Monograph 3, p. 133-150.

Laycock, A.H. 1979 'Competitive Useage Perspectives' in Proc. Conf. Alberta Water Resources: Present and Future, Alberta Chamber of Commerce, Red Deer, Alberta, 21 pp.

Leaf, C.F. 1975 Watershed Management in the Rocky Mountain Subalpine Zone: The Status of Our Knowledge, USDA For. Serv. Res. Paper RM-137, Fort Collins, Colorado, 31 pp.

Leaf, C.F. and G.E. Brink 1972 'Simulating Effects of Harvest Cutting on Snowmelt in Colorado Subalpine Forest', in Nat. Symp. on Watersheds in Transition, Fort Collins, A.W.R.A., p. 191-196.

Lester, P.F. 1976 A Quantitative Definition of the Chinook of Southern Alberta, unpub. report, Environmental Sciences Centre, Univ. of Calgary, Calgary, 28 pp.

Lester , P.F. 1974 'Climatology', in The Mountain Environment and Urban Society - Kananaskis Pilot Study, Environmental Sciences Centre, University of Calgary, Calgary, p. 151-192.

Linsley, R.K., M.A. Kohler and J.L.H. Paulhus 1949 Applied Hydrology, McGraw-Hill, New York.

Longley, R.W. 1967a 'Climate and Weather Patterns', in Alberta/A Natural History, W.G. Hardy (ed.), M.G. Hurtig Publishers, Edmonton, p. 53-67.

Longley, R.W. 1967b 'The Frequency of Winter Chinooks in Alberta', in Atmosphere, Vol. 5, p. 4-16.

Longley, R.W. 1972 The Climate of the Prairie Provinces, Environment Canada, Atmospheric Environment Service, Climatological Studies, No. 13, Toronto, 79 pp.

Louie, P.Y.T. 1977 'Potential Evaporation Loss from Snow in Southeastern Alberta', in Proc. Canadian Hydrology Supp. Edmonton, Assoc. Comm. Hydrology, Nat. Res. Council, Ottawa.

Lynch, J.A., W.E. Sopper and D.B. Partridge 1972 'Changes in Streamflow Following Partial Clearcutting on a Forested Watershed' in Nat. Symp. on Watersheds in Transition, Fort Collins, A.W.R.A., p. 313-320.

MacHattie, L.B. 1963 'Winter Injury of Lodgepole Pine Foliage', in Weather, Vol. 18, No. 10, p. 301-307.

MacHattie, L.B. 1968 'Kananaskis Valley Winds in Summer', in Jour. Applied Meteorlogy, No. 7, p. 348-352.

MacHattie, L.B. 1970 'Diurnal Temperatures in the Kananaskis Valley in Summer', in Jour. of Applied Meteorology, Vol. 9, No. 4, p. 574-582.

Maclaren Plansearch 1982, personal communication, Dr. Brian Bietz, Senior Aquatic Scientist, Calgary.

Mann, A.S. 1964 'Meteorological Instrumentation in Marmot Creek Basin', in Proc. Hydrology Symp. on Research Watersheds, Appendix III, Guelph, p. 123-130.

Marsh, J.S. 1965 The Chinook and Its Geographic Significance in Southern Alberta, unpub. thesis (M.Sc.), University of Alberta, Calgary, 99 pp.

Marsh, J.S. 1969 Man and Landscape Change in Banff National Park, unpub. thesis (Ph.D.), Department of Geography University of Calgary, Calgary, Alberta.

Marshall, J.R. 1922 Kananaskis Lakes - Palliser River Map - Area, Canada, Dept. of Mines, Geol. Surv. Summary Report, Part B.

Martinelli, M. 1964 'Influence of Gap Width Below a Vertical Slat Snow Fence on Snow and Location of Lee Drift' in Int. Assoc. Sci. Hydrology Bulletin, 9(4), p. 48-57.

Martinelli, M. 1965a 'Accumulation of Snow in Alpine Areas of Central Colorado and Means of Influencing It', in Journal of Glaciology, 5, p. 625-636.

Martinelli, M. 1965b 'An Estimate of Summer Runoff from Alpine Snowfields', in Journal of Soil and Water Conservation, 20, p. 24-46.

Martinelli, M. 1972 'Snow Fences for Influencing Snow Accumulation', in Int. Symp. Role of Snow and Ice in Hydrology, W.M.O., 5, Banff, Alberta.

Martinelli, M. 1975 Water Yield Improvement from Alpine Areas: The Status of Our Knowledge, U.S.D.A. Forest Service, Research Paper RM-138, Fort Collins, Colorado, 16 pp.

Meiman, J.R. and T.L. Dietrich 1975 'Hydrology of Patch Cuts in Lodgepole Pine' Jour. Irrig. Drain. Div., Proc. Am. Soc. Civil Eng., 101(IRI), p. 41-52.

Munn, R.E. and D. Storr 1967 'Meteorological Studies in the Marmot Creek Watershed, Alberta, Canada', in Water Resources Research, 3, p. 713-722.

Neill, C.R. 1977 Water Management for Increased Water Yield Report to Oldman River Basin Study Management Committee, Lethbridge

Neill, C.R. 1980 'Forest Management for Increased Water Yield - How Useful in Southern Alberta?', in Canadian Water Resources Journal, Vol. 5, No. 1, U. of T. Press, Toronto, p. 56-75

Neill, C.R., D.J. Bray, M.F. Schouten and J.R. Card 1970 Selected Characteristics of Streamflow in Alberta, Research Council of Alberta, River Engineering and Surface Hydrology Report 70-1

Nelson, J.S. 1965 'Effects of Fish Introductions and Hydro-Electric Development on Fishes in the Kananaskis River System, Alberta', in Jour. Fish Res. Bd. Canada, 22(3)., p. 721-753

Nowicki, J.J. 1972 Kananaskis - Spray District, Phase 1 Preliminary Analysis, Foothills Resource Allocation Study, Forest Land Use Branch, Multiple Use Planning Section, Alberta Forest Service, Edmonton

Olmstead, A.D. 1974 'Influence of Urban Society' in The Mountain Environment and Urban Society - Kananaskis Pilot Study, Kananaskis Centre for Environmental Sciences Publication, University of Calgary, Calgary, p. 311-343

Oltman, R. and J. Brehaut 1974 'Enviromental History', in The Mountain Environment and Urban Society - Kananaskis Pilot Study, Kananaskis Centre for Environmental Sciences Publication, University of Calgary, Calgary, p. 17-52.

Osborn, G.D. and L.E. Jackson 1974 'Physical Environment' in The Mountain Environment and Urban Society - Kananaskis Pilot Study, Kananaskis Centre for Environmental Sciences Publication, University of Calgary, Calgary, p. 52-150.

Packer, P.E. 1960 'Some Terrain and Forest Effects on Maximum Snow Accumulation in a Western White Pine Forest', in Proc. 28th Annual Western Snow Conference, p. 63-66.

Packer, P.E. 1962 'Elevation, Aspect, and Cover Effects on Maximum Snowpack Water Content in a Western White Pine Forest', in Jour. Forest Science, Vol. 8, No. 3, p. 225-235.

Packer, P.E. 1971 'Terrain and Cover Effects on Snowmelt in a Western White Pine Forest', in Jour. Forest Science, Vol. 17, No. 1, p. 125-134.

Percy, D.R. 1981 Legal and Jurisdictional Aspects of Interbasin Transfers, Canadian Water Resources Journal, Vol. 6, No. 2, p. 1-12.

Plain, R.H.M. 1981 Policy Perspectives on Water Resource Development in Alberta with Specific Reference to Regional Development, and the Economic Aspects of Alberta Heritage Fund Expenditure on Inter-Basin Transfers of Water, Canadian Water Resources Journal, Vol. 6, No. 2, p. 28-42.

Phillips, W., McMillan, M. and T. Veeman 1981 Evaluation of the Oldman River Basin Irrigation Proposals: Implication for Interbasin Transfers, Canadian Water Resources Journal, Vol. 6, No. 2, p. 54-61.

Poliquin, W.H. 1968 Some Climatic Data for the East Slopes of the Rockies in Alberta, Management Report No. 2, Eastern Rockies Forest Conservation Board, Calgary, 7 pp.

Poliquin, W.H. and W.R. Hanson 1973 Precipitation on the East Slopes of the Rockies in Alberta, as Measured by a Storage Gauge Network, Eastern Rockies Forest Conservation Board, Management Report No. 3, 12 pp.

Powell, J.M. 1973 Climate in the Kananaskis Forest Experiment Station, C.L. Kirby (ed.), Canadian Forestry Service, Environment Canada, Northern Forest Research Centre, Info. Report NOR-X-51, 50 pp.

Powell, J.M. 1977 'Precipitation Climatology of the Eastern Slopes Area of Alberta', in Proc. Alberta Watershed Research Program Symp., R.H. Swanson (ed.), p. 187-204.

Redmond, D.R. 1964 'Organization of Inter-Agency Watershed Research Programs for Canada', in Proc. Symp. on Hydrology and Research Watersheds, No. 4, Guelph, Ontario, p. 299-304.

Rothwell, R.R. 1971 Watershed Management Guidelines for Logging and Road Construction, Info. Report A-X-42, Forest Research Laboratory, Canadian Forestry Service, Edmonton, 78 pp.

Rutter, N.W. 1965 Surficial Geology of the Banff Area, unpub. thesis (Ph.D.), University of Alberta, Edmonton, 105 pp.

Rutter, N.W. 1968 A Method for Predicting Soil Erosion in the Rocky Mountain Forest Reserve, Alberta, a Geol. Survey Can., Paper No. 67-67, 32 pp.

Sigvaldson, O.T. 1975 The Trent River System: An Improved Operational Strategy, paper presented at the Second World Congress on Water Resources, New Delhi, India, 42 pp.

Smith, R.F. 1977 'Irrigation Demands on East Slopes Water', in Proc. Symp. Alberta Watershed Research Program, Info. Report NOR-X-176, Northern Forest Research Centre, Edmonton, p. 32-49.

Sneyd, A.R. 1976 'Testing the Performance of the Trent Basin Simulation Model', in Hydrologic Studies in the Peterborough Area, Trent Student Geographer, P.M. Ecclestone (ed.), Vol. 4, No. 5, Peterborough, Ontario, p. 24-44.

Sopper, W.E. and H.W. Lull (eds.) 1965 'Forest Hydrology', in Proc. Symp. Int. Forest Hydrology, Permagon Press.

Stalker, A.M. 1973 Surficial Geology of the Kananaskis Research Forest and Marmot Creek Basin Region of Alberta, Geol. Survey Can., Paper No. 72-51, 25 pp.

Stanton, C.R. 1966 'Preliminary Investigation of Snow Accumulation and Melting in Forested and Cut-Over Areas of the Crowsnest Pass', in Proc. 34th Annual Meeting Western Snow Conference, p. 7-12.

Stevenson, D.R. n.d. unpublished research reports, Research Council of Alberta, Edmonton, Alberta.

Stevenson, D.R. 1967 Geological and Groundwater Investigations in the Marmot Creek Experimental Basin of Southwestern Alberta, Canada, unpub. thesis (Ph.D.), University of Alberta, Edmonton.

Stevenson, D.R. 1974 Preliminary Analysis of Groundwater Flowsystems in Marmot Creek and Streeter Basins, Internal Report, Groundwater Division, Alberta Research Council, Edmonton, Alberta

Storr, D. 1963 Maximum One-Day Rainfall Frequencies in Alberta, Canada, Dept. of Transport Meteorological Branch, Toronto, CIRC 3796, TEC-451, 25 pp.

Storr, D. 1967 'Precipitation Variations in a Small Forested Watershed', in Proc. 35th Annual Meeting, Western Snow Conference, Boise, Idaho, p. 11-17.

Storr, D. 1968 'An Estimate of Snow Evaporation Potential on Marmot Basin', in Proc. National Workshop Seminar on Snow Hydrology, Fredriction, N.B., 7 pp.

Storr, D 1969 'Precipitation map of East Slopes Area, Alberta' in P.J.B. Duffy and Z. Nemeth, A Forest Land Capability Classification for the East Slopes Area, Alberta, For. Res. Lab. Info. Report A-X-20, Calgary, 19 pp.

Storr, D. 1972 'Estimating Effective Net Radiation for a Mountainous Watershed' Boundary Layer Meteorology, Vol. 3, No. 4, p. 3-14.

Storr, 1974a Monthly and Annual Estimates of Evapotranspiration at Marmot Creek Alberta by the Energy Budget Method, CMRR 4/74, Atmospheric Environment Service, Downsview, Ontario.

Storr, D. 1974b Relating Sub-Surface Water Storage to Streamflow in a Mountainous Watershed, CMRR 6/74, Atmospheric Environment Service, Downsview, Ontario, 14 pp.

Storr, D. 1977 'Some Preliminary Water Balances of Marmot Creek Sub-basin in Swanson, R.H. and P.A. Logan, (eds.) Symp. Proc., Alberta Watershed Research Program, Information Report NOR-X-176, p. 1-19.

Storr, D. 1979 'A Comparison of Daily Snowmelt by the U.S. Corps of Engineers Theoretical Model with Measured Amounts on a Snow Pillow', in Proc. Symp. Cold Climate Hydrology, Assoc. Comm. on Hydrology, Nat. Res. Council, Vancouver, B.C., 11 pp.

Storr, D. and H.R. Ferguson 1972 'Distribution of Precipitation in Some Mountainous Canadian Watersheds', in Distribution of Precipitation in Mountainous Areas, World Meteorol. Organ., Geneva, WMO Rep. 326, Vol. II, p. 243-263.

Storr, D. and D.L. Golding 1976 'Comparison of Precipitation-Gauge and Snow Pillow Data from a Severe April Snowstorm in a Mountain Watershed', in Proc. 44th Annual Western Snow Conference, Calgary, Alberta, p. 78-86.

Swanson, R.H. (ed.) 1977 'The Alberta Watershed Research Program', in the Proc. Symp. Alberta Watershed Research Branch, Environment Canada, Edmonton, 342 pp.

Swanson, R.H. and G.R. Hillman 1977 Effect of Large-Scale Clear Cutting on Water Yield in Western Alberta' in Proc. Supp. Alberta Watershed Research Program, Swanson and Logan (eds.) Northern Forest Research Centre, Info. Rep. NOR-X-176, Edmonton, p. 256-271.

Tennant, D.L. 1976 Instream Flow Regimes for Fish, Wildlife, Recreation and Related Environmental Resources, in Fisheries, Vol. 1, No. 4, p. 6-10.

TransAlta Utilities 1980, Power for Progress, Public Affairs Department, Calgary, 16 pp.

TransAlta Utilities 1981, Some Facts: 1980 Information booklet prepared by the Public Affairs Department, TransAlta Utilities, Calgary, 17 pp.

TransAlta Utilities Inc. 1982, personal communication, Pat Doyle concerning water management licenses, Water Management Division, Calgary.

TransAlta Utilities 1982, Interim Report: December, 1981 an annual summary of income and expenditures, TransAlta Utilities, Calgary.

U.S. Dept. of the Interior 1971 Project Skywater: Colorado River Basin Pilot Project, Div. of Atmospheric Water Resources, Bureau of Reclamation, Denver.

Wagner, A.A. 1957 'The Use of United Soil Classification System by the Bureau of Reclamation', in Proc. 4th Int. Conf. Soil Mechanics Found., London, Vol. I, p. 125.

Walker, M.J.C. 1971 Late Wisconsin Ice Near Morley, Alberta, unpub. thesis (M. Sc.), University of Calgary, 115 pp.

Wierenga, A., 1982 Correspondence re: TransAlta Proposal for Increasing Peaking Power Output, Renewable Resources Study Group. Public Advisory Committee, Environment Council of Alberta, Edmonton, 9 pp.

Wilm, H.G. and E.G. Dunford 1941 Problem Analysis - Region 2 U.S. Forest Service, Rocky Mountain Forest and Range Experiment Station, Fort Collins, Colorado, 77 pp.

Wilm, H.G. and E.G. Dunford 1948 Effect of Timber Cutting on Water Available for Streamflow from a Lodgepole Pine Forest, U.S. Dept. of Agric., Tech. Bull. 968, p. 43.

Wyldman, E. 1977 Watershed Management and Political Realities, paper presented at Alberta Watershed Research Program Symposium and published later as "A Policy for Resource Management of the Eastern Slopes', Alberta, Energy and Natural Resources, Edmonton.

B30353